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PILOT'S AND NAVIGATOR'S HANDBOOK FOR CIVIL  
AVIATION (SELECTED ARTICLES)

G. V. Markov, et al

Foreign Technology Division  
Wright-Patterson Air Force Base, Ohio

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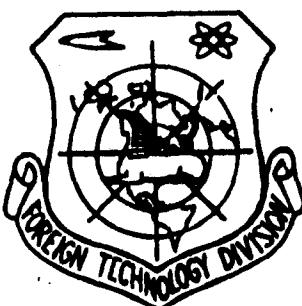
## FOREIGN TECHNOLOGY DIVISION



PILOT'S AND NAVIGATOR'S HANDBOOK FOR CIVIL AVIATION  
(SELECTED ARTICLES)

by

G. V. Markov and L. A. Ostrogskiy



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13. ABSTRACT

This is a handbook for civilian pilots and navigators. It is based both on US and Soviet systems and includes instructions and operating procedures relative to the following: air navigation, international air routes, compass error, course systems, great circle navigation, various navigation instruments, Doppler radar system, azimuth and range system. Foreign (non-Soviet) electronic short-range navigation systems VOR, TACAN, VORTAC, DME, VRM-5 and consol systems, long-range navigation systems (CYTAC, DECCA, DECTRA), airborne KURS-MP-1 navigation and landing equipment, BSU-ZP airborne control system, the NL-10m navigation slide rule, and the NRK-2 navigation calculator. General information and trouble shooting instructions are given for the RBP-4, RPSN-2, GROZA, and ROZ-1 radar sets. Various methods of celestial navigation are discussed briefly.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Air Navigation Altimeter Navigation Compass Radio Deviation Doppler Radar Azimuth System Radio Beacon Decca System Dectra System Gyroscopes KURS-MP-1 System						

1b  
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Translator's note: On several occasions, symbols found in formulae and calculations appear to have been rendered incorrectly in the original document. They will be shown exactly as they appear in the original.

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All figures, graphs, tables, equations, etc.  
merged into this translation were extracted  
from the best quality copy available.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	А а	А, a	Р р	Р р	Р, r
Б б	Б ё	B, b	С с	С ѿ	S, s
В в	В ' ѿ	V, v	Т т	Т ѿ	T, t
Г г	Г ѿ	G, g	У у	У ѿ	U, u
Д д	Д ѿ	D, d	Ф ф	Ф ѿ	F, f
Е є	Е є	Ye, ye; E, e*	Х х	Х ѿ	Kh, kh
Ж ж	Ж ѿ	Zh, zh	Ц ц	Ц ѿ	Ts, ts
З з	З ѿ	Z, z	Ч ч	Ч ѿ	Ch, ch
И и	И и	I, i	Ш ш	Ш ѿ	Sh, sh
Я я	Я я	Y, y	Щ ѿ	Щ ѿ	Shch, shch
К к	К к	K, k	҃ ѿ	҃ ѿ	"
Л л	Л ѿ	L, l	҄ ѿ	҄ ѿ	Y, y
М м	М ѿ	M, m	҅ ѿ	҅ ѿ	E, e
Н н	Н ѿ	N, n	҆ ѿ	҆ ѿ	Yu, yu
О о	О о	O, o	҇ ѿ	҇ ѿ	Ya, ya
П п	П п	P, p	҈ ѿ	҈ ѿ	

\* ye initially, after vowels, and after ѿ, ѿ; є elsewhere.  
When written as є in Russian, transliterate as yє or є.  
The use of diacritical marks is preferred, but such marks  
may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH  
 DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	$\sech^{-1}$
arc csch	$\csch^{-1}$
rot	curl
lg	log

LIST OF ABBREVIATIONS AND ACCEPTED  
CONVENTIONAL DESIGNATIONS

AAE -	AAE - Air Almanac
АГД -	AGD - azimuth gyro sensor
АЗС -	AZS - circuit breaker
АК -	AK - astroc' rection
АЛП -	ALP - astronomical line of position
АНУ -	ANU - automatic navigation equipment
АП -	AP - automatic pilot
АРК -	ARK - automatic radio compass
АРЧ -	ARCh - automatic frequency control
БПРМ -	BPRM - inner marker beacon
БУ -	BU - lateral deviation or control unit
БКН -	BKN - airborne celestial charts
ВПП -	VPP/RW - runway
ГД -	GD - horizontal range
ГО -	GO - main orthodrome
ГПК -	GPK - directional gyroscope
ГРП -	GRP - expansion unknown [chief radiodispatcher point/gyroscope radio point]
ДИСС -	DISS - Doppler speed and drift meter
ДПРМ -	DPRM - outer marker beacon
ЗИ ПУ -	ZI PU - given true course angle
ЗМП -	ZMP - given magnetic bearing
ЗМПУ -	ZMPU - given magnetic course angle
ЗОС -	ZOS - ground aids to navigation
ЗПУ -	ZPU - given course angle
ИК -	IK - true course
ИКАО -	ICAO - International civil aviation organization
ИКО -	IKO - plan-position indicator
ИПМ -	IPM - departure point
ИПР -	IPR - true bearing of a radio station
ИПС -	IPS - true bearing of aircraft

ИПУ -	IPU - true course angle
КВ -	KV - short wave
КГГ -	KGG - expansion unknown
КК -	KK - compass course
КМ -	KM - correction mechanism
КО -	KO - reference landmark
КПМ -	KPM - route check point/destination check point
КПП -	KPP - route check point/combined flight instrument
КР -	KR - shortest distance
КРП -	KRP - compass radio point
КС -	KS - course system
КУВ -	KUV - angle between course and wind direction
КУО -	KUO - reference point angle of approach
КУР -	KUR - radio station angle of approach
КУС -	KUS - combined airspeed indicator
ЛБУ -	LBU - course-line direction
ЛЗП -	LZP - specified track
ЛУР -	LUR - linear turn lead
МК -	MK - magnetic course
МПР -	MPR - magnetic bearing of a radio station
МПС -	MPS - magnetic bearing of aircraft
МПУ -	MPU - magnetic course angle
МС -	MS - aircraft position/magnetic declination
НВ -	NV - navigation computer
НД -	ND - slant range
НПП ГА -	NPP GA - flight manual of civil aviation
НРК-2 -	NRK-2 - Kalashnikov navigational computer
ОЗПУ -	OZPU - expansion unknown
ОК -	OK - reverse course/orthodromic course
ОМПУ -	OMPU - great circle magnetic track angle
ОПР -	OPR - reciprocal bearing of radio station
ОПРС -	OPRS - reciprocal bearing of radio station
ОПС -	OPS - reciprocal bearing of aircraft

ОПУ -	OPU - great circle track angle
ОПУМ -	OPUM - orthodromic meridian course angle
ОРК -	ORK - radio compass reading
ОСП -	OSP - instrument landing system
ПМПУ -	PMPU - landing (magnetic) track angle
ПП -	PP - track bearing
ППДА-Р -	PPDA-P - pilot's direct-reading range and azimuth instrument
ППДА-Ш -	PPDA-Sh - Navigator's direct-reading range and azimuth instrument
ППМ -	PPM - route turning point
ППС -	PPS - expansion unknown
ПУ -	PW - control panel/track angle
РБ -	RB - blocking relay
РВС -	RVS - radio broadcasting station
РМИ -	RMI - radiomagnetic indicator
РНТ -	RNT - radio check point
РПСН -	RPSN - expansion unknown
РРЧ -	RRCh - manual frequency control
РСБН -	RSBN - short-range radio navigation system
РСП -	RSP - expansion unknown
САИ НГА -	SAI NGA - Aviation Information Service of the Ministry of Civil Aviation
СВОД -	SVOD - Lead
СИ -	SI - true north
СПУ -	SPU - aircraft intercom system
СРП -	SRP - computer device
ТВА -	TVA - Tables of altitudes and azimuth of the sun, moon, and planets
ТВАЗ -	TVAZ - Tables of altitudes and azimuths of the stars
ТВГ -	TVG - entrance point to glide path
ТНВ -	TNV - outside air thermometer
ТРи -	TRM - expansion unknown
ТУЕ -	TUE - universal electric thermometer
УВ -	UV - wind angle

УГА - UGA - gyro unit indicator  
УК - UK - course indicator  
УНГ - UNG - tilt angle, angle of slope  
УП - UP - turn indicator/turn angle  
УС - US - drift angle  
УУ - UU - lead angle  
УШ - USh - navigator's indicator  
УША - UShA - expansion unknown  
УШМ - UShM - navigator's magnetic indicator  
ФМПУ - FMPU - actual magnetic course angle  
ЦГВ - TsGV - master vertical gyro  
ЦРШ - TsRSh - navigator's control circuit  
ЧО - ChO - particular orthodrome  
ЩП - ShchP - pilot's panel  
ЩУ - ShchU - control panel  
ЮИ - Uyi - true south

## FIFTH SECTION

### AIR NAVIGATION

#### SEPARATION

The altimeter setting rules during flights over USSR territory. The echelons of flights (Figs. 41 and 42) are established from a conditional level, which corresponds to the level of the Baltic sea at standard atmosphere (atmospheric pressure 760 mm Hg at free-air temperature +15°C with temperature gradient 0.65°C and normal humidity).

Table 15 shows the order of numbering of echelons.

The altitude of the echelon in flight is determined by a barometric altimeter with setting of graduation "760" of the barometric scale opposite the fixed index. Before takeoff the crew is obligated to set the readings of the barometric altimeter (altimeters) to "zero" altitudes by means of setting the magnitude of atmospheric pressure (at the level of the runway of the takeoff airfield) opposite the fixed index.

The setting of the barometric pressure scale of the altimeter with graduation "760" opposite the fixed index is permitted only after the gaining of the transfer altitude - altitude of rectangular route legalized for a given airfield.

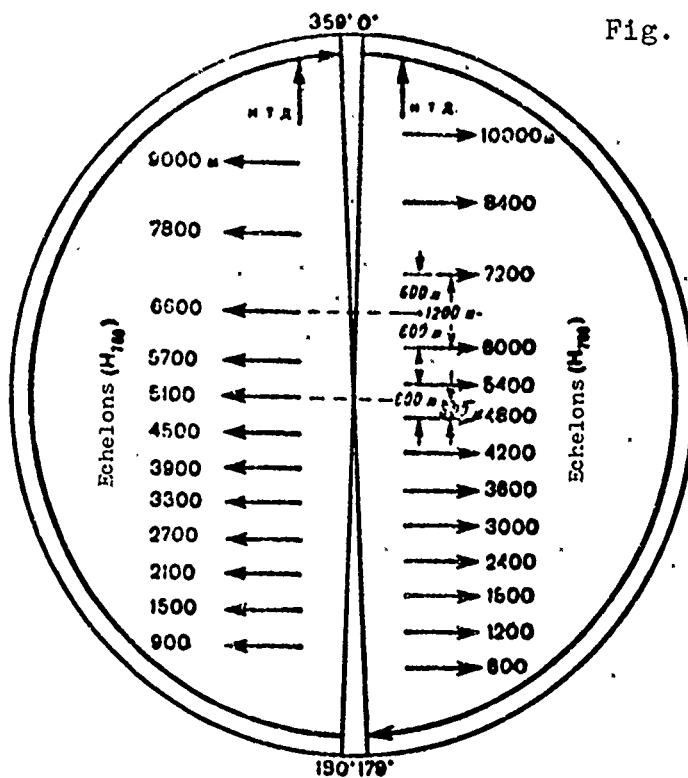


Fig. 41. Diagram of vertical separation of aircraft depending on the geographical heading

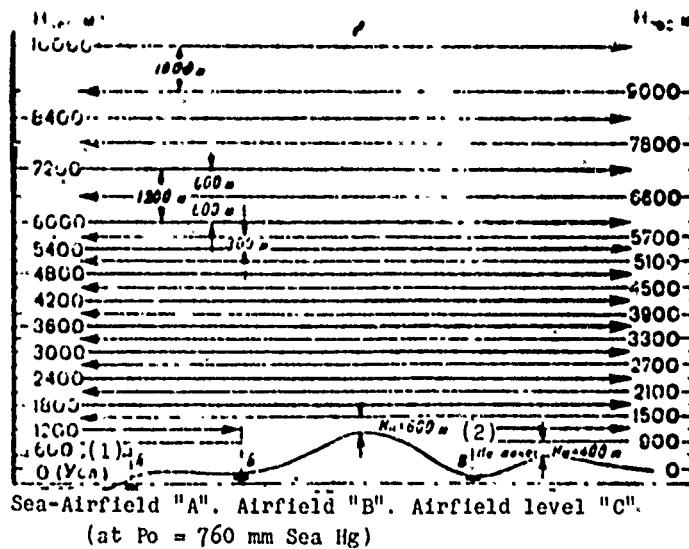


Fig. 42. Diagram of vertical separation of aircraft in vertical plane.  
KEY: (1) (Cond.); (2) Not less than:

Table 15. The order of numbering of echelons

The second (western) semicircle of directions of air lines from 180 to 359°		The first (Eastern) semicircle of directions of air lines from 0 to 179°	
No. of echelon	Altitude of echelon	No. of echelon	Altitude of echelon
9	900	66	600
15	1500	12	1200
21	2100	18	1800
27	2700	24	2400
33	3300	30	3000
39	3900	36	3600
45	4500	42	4200
51	5100	48	4800
57	5700	54	5400
63	6300	60	6000
78	7800	72	7200
90	9000	84	8400
110	11000	100	10000
130	13000	120	12000
etc.	etc.	etc.	etc.

During landing approach to the airport the readjustment of the barometric scale of the altimeter from pressure 760 mm Hg to the airfield elevation pressure is permitted with departure from the altitude of the transfer echelon - the lower echelon of the holding area of the landing airfield.

Before landing at high-mountain airfields with the obtaining on board of a report about atmospheric pressure at the level of the airfield runway less than 670 mm Hg it is necessary to leave the graduation "760" of the barometric pressure scale opposite the fixed index, to find the difference between barometric pressure 760 and barometric pressure at the runway level of the landing airfield and to express it in meters with respect to standard atmosphere. The magnitude found in this way will be the zero of the altimeter.

**Calculation of lower echelon.** For determining the altitude of the lower echelon in flight along a route it is necessary to calculate the safe altitude by formula

$$H_{\text{t}, \text{c}, \text{v}} = H_{\text{u}} + H_{\text{p}} + \\ + (760 - p_{\text{min}}) \frac{11}{100} \Delta H_{\text{t}}$$

where  $H_{\text{u}}$  - the true altitude of flight, established for a given route in accordance with the requirements for the flight manual (NPP) of civil aviation (GA);  $H_{\text{p}}$  - the absolute altitude of the highest point of relief, including the altitude of artificial obstructions at a certain distance from the axis of the route;  $\Delta H_{\text{t}}$  - systematic temperature correction on to the altimeter;  $p_{\text{min}}$  - the minimum atmospheric pressure on the route, reduced to sea level.

The lower safe echelon will be the first echelon, greater than the safe altitude of flight (see Fig. 42).

Example. The safe altitude, obtained from calculations, is 1955 m. For flights with courses within limits from 0 to  $179^{\circ}$  the altitude of the lower echelon will be 2400 m, while for flights with courses (track angles) within limits from  $180$  to  $359^{\circ}$  - 2100 m.

#### DISTINCTIVE FEATURES OF SEPARATION AND AIR NAVIGATION ON INTERNATIONAL AIR ROUTES

Organization and direction of flights on international air routes. The routes passing over the territories of two or more states are called international.

The features of flights on international routes are determined by the rules and norms established by the appropriate states, which include:

- conditions of crossing of state boundaries;
- width of air routes;
- system of separation of aircraft;
- restrictions and zones with special flight conditions;

airborne and ground documentation, which regulates flights; facilities and rules of air navigation, communications and signaling; time reckoning systems; norms of fuel reserve; airport network.

In all states the movement control services are state organizations and direct the flights of all aircraft, including foreign.

The communication with the aircraft is conducted mainly on ultrashort waves by radiotelephone in the languages established for the territories of the given states.

In the countries having entered the international civil aviation organization (ICAO), radio communication with foreign aircraft is conducted in the English language.

When accomplishing international flights on every aircraft there should be:

evidence of its airworthiness;  
confirmed flight plan;  
weather report.

The rules of flights over different foreign states are different. Detailed information about conditions, diagrams and flight routes on separate international routes is stated in special collections, published by the aviation information service of the Ministry of civil aviation of the USSR (SAI MGA).

In the countries entering the ICAO the direction of air traffic has mainly an informational nature. The crew is given

the altitude, the precise takeoff and arrival time, and sometimes the time of flight over the check points. The remaining data are transmitted on board the aircraft in the form of information, on the basis of which the crew makes independent decisions concerning the execution of flight.

Foreign air routes, as a rule, have a width of 10 nautical miles (18.52 km). This magnitude determines the required accuracy of air navigation.

In the states entering the ICAO on air routes there are used units of measure which differ from those accepted in the USSR. Therefore the airplane crews, executing international flights, should have tables or charts for the conversion of some units of measure into others.

Units of measure accepted in the countries entering the ICAO and in the USSR are given in Table 16. The "Blue table" graph pertains to those countries which still have not completely applied the recommendations of the ICAO for the units of measure.

**Foreign systems of aircraft separation.** In various states different systems of separation are used. However, for international flights almost everywhere there is already accepted the main, adopted in the USSR, principle of the reading of barometric altitudes of separation from the level of the isobaric surface, which corresponds to standard pressure 760 mm Hg.

The distribution of the altitudes of separation depending on the heading can be different in various states. Semicircular and quadrant systems are used.

**Semicircular system** (Table 17) is used mainly in the USSR and USA. In the USA for flight altitudes up to 29,000 feet the

Table 16. The units of measure accepted in the USSR and countries entering the ICAO.

Measured magnitudes	Units of Measure		USSR
	ICAO	"Blue tabl."	
Distance	Nautical miles with tenths	Nautical miles with tenths	Kilometers
Altitude, dimensions of airfields and short distances	Meters	Feet	Meters
Horizontal speed	Knots	Knots	Kilometers per hour
Vertical speed	Meters per second	Feet per minute	Meters per second
Wind velocity	Knots	Knots	Kilometers per hour
Direction of wind vector	True degrees	True degrees	True degrees (reciprocal to the wind vector).
Direction of wind vector for takeoff and landing	Magnetic degrees	Magnetic degree.	Magnetic degrees
Cloud height	Meters	Feet	Meters
Visibility	Kilometers, meters	Nautical miles, yards	Kilometers, meters
Barometric pressure	Millibars	Millibars	Millimeters of mercury column
Temperature	Degrees centigrade	Degrees centigrade	Degrees centigrade
Weight	Kilograms	Pounds	Weight
Time	Hours, minutes	Hours, minutes	Hours, minutes
The fuel quantity	Gallons	Gallons	Liters, kilograms

intervals between parallel echelons are taken equal to 2000 feet, and between opposing - 1000 feet. For flight altitudes from 29,000 feet and more the corresponding intervals are doubled. During flights in the direction of track angles from 0 to  $179^\circ$ , i.e., to the east, there are assigned separation altitudes, in multiples of odd thousands of feet. During flights with track angles from  $180$  to  $359^\circ$ , i.e., to the west, even echelons are assigned.

Table 17. Table of semicircular separation,  
accepted by a number of countries - members of ICAO.

Magnetic courses						Magnetic courses					
By instruments			Visually			By instruments			Visually		
No. of echelon	Altitude		No. of echelon	Altitude		No. of echelon	Altitude		No. of echelon	Altitude	
	Feet	Meters		Feet	Meters		Feet	Meters		Feet	Meters

Magnetic heading 0-179° Magnetic heading 150-359°

10	1 000	300	15	1 500	450	20	2 000	600	25	2 500	750
30	3 000	900	35	3 500	1 050	40	4 000	1 200	45	4 500	1 350
50	5 000	1 500	55	5 500	1 700	60	6 000	1 850	65	6 500	2 000
70	7 000	2 150	75	7 500	2 300	80	8 000	2 450	85	8 500	2 600
90	9 000	2 750	95	9 500	2 900	100	10 000	3 050	105	10 500	3 200
110	11 000	3 350	115	11 500	3 500	120	12 000	3 650	125	12 500	3 800
130	13 000	3 950	135	13 500	4 100	140	14 000	4 250	145	14 500	4 400
150	15 000	4 550	155	15 500	4 700	160	16 000	4 900	165	16 500	5 050
170	17 000	5 200	175	17 500	5 350	180	18 000	5 500	185	18 500	5 650
190	19 000	5 800	195	19 500	5 950	200	20 000	6 100	205	20 500	6 250
210	21 000	6 400	215	21 500	6 550	220	22 000	6 700	225	22 500	6 850
230	23 000	7 000	235	23 500	7 150	240	24 000	7 300	245	24 500	7 450
250	25 000	7 600	255	25 500	7 750	260	26 000	7 900	265	26 500	8 100
270	27 000	8 250	275	27 500	8 400	280	28 000	8 550	285	28 500	8 700
290	29 000	8 850	300	30 000	9 150	310	31 000	9 450	320	32 000	9 750
330	33 000	10 650	340	34 000	10 350	350	35 000	10 650	360	36 000	10 950
370	37 000	11 300	380	38 000	11 600	390	39 000	10 950	400	40 000	12 200
410	41 000	12 500	420	42 000	12 800	430	43 000	13 100	440	44 000	13 400
450	45 000	13 700	460	46 000	14 000	470	47 000	14 350	480	48 000	14 650
490	49 000	14 950	500	50 000	15 250	510	51 000	15 550	520	52 000	15 850

In some countries, having entered the ICAO, including England, Belgium, Denmark, Sweden, Holland and others, the quadrant system (Table 18) is accepted, according to which at altitudes up to 29,000 feet the parallel echelons differ by 2000 feet, and opposing - 1000 feet. The echelons for headings, which correspond to adjacent quadrants, are distinguished from each other with respect to altitudes by 500 feet.

At altitudes over 29,000 feet the corresponding intervals are doubled.

Table 18. Table of quadrant separation according to ICAO.

No. of echelon	Meters	No. of echelon	Meters
25	750	10	300
45	1350	30	900
65	2000	50	1350
85	2650	70	2150
105	3200	90	2750
125	3800	110	3350
145	4400	130	3950
165	5050	150	4550
185	5650	170	5200
205	6250	190	5800
225	6850	210	6400
245	7450	230	7000
265	8100	250	7600
285	8700	270	8250
305	9750	290	8850
325	10950	330	10050
345	12200	370	11300

Table 19. Conversion of the numbers of echelons into meters according to ICAO (No. of echelons in ascending order).

No. of echelon	Meters	No. of echelon	Meters
10	300	180	5500
15	450	185	5650
20	600	190	5800
23	750	195	5950
30	900	200	6100
35	1050	205	6250
40	1200	210	6400
45	1350	215	6550
50	1500	220	6700
55	1700	225	6850
60	1850	230	7000
65	2000	235	7150
70	2150	240	7300
75	2300	245	7450
80	2450	250	7600
85	2600	255	7750
90	2750	260	7900
95	2900	265	8100
100	3050	270	8250
105	3200	275	8400
110	3350	280	8550
115	3500	285	8700
120	3650	290	8850
125	3800	300	9150
130	3950	310	9450
135	4100	320	9750
140	4250	330	10050
145	4400	340	10350
150	4550	350	10650
155	4700	360	10950
160	4900	370	11300
165	5050	380	11600
170	5200	390	11900
175	5350	400	12200

### COMPASS DEVIATION

As a result of investigations the following was established:

at the place of installation of inductive or magnetic sensors on contemporary aircraft with gas-turbine engines the deviation does not exceed  $\pm 1^\circ$ ;

compass swinging cannot be performed at airfields which have reinforced concrete coating, since there are local anomalies there which cause change in the readings of magnetic compasses and course systems up to  $\pm 5-8^\circ$ ;

replacement of gas-turbine engines on the aircraft does not affect the accuracy of operation of the course systems and distant-reading compasses.

On this basis there have been published special instructions for the various types of heavy transport planes with gas-turbine engines, according to which:

compass swinging from periodic servicing with respect to maintenance of the given aircraft has been eliminated;

the deviational microadjuster has been removed from the sensors of distant-reading compasses and course systems;

it is recommended to compensate the instrument errors of distant-reading compasses and course systems only during the replacement of the UShM indicator (DGMK-7 compass) or the correction mechanism;

the adjustment error of sensors is determined by turning the sensor to matching of the course readings on the navigator's indicator with the magnetic course of the aircraft, determined by twofold direction finding of his longitudinal axis (from the nose and tail).

The compensation of instrument errors of course devices is accomplished without rotation of the aircraft in the following order.

a) On aircraft equipped with KS course systems and GIK-1 gyro-induction compass:

remove the induction sensor from the aircraft and fasten it on the rotating antimagnetic platform of the UPK-3 assembly. Connect the sensor with the course system with a connecting band. Install the platform of the antimagnetic installation with the sensor fastened to it on the wing of the aircraft over the attachment point of the induction sensor or on a tripod when carrying out the installation to the ground;

set the zero reading on the navigator's indicator dials and the correction mechanism.

The mean error in teletransmission on the section sensor - correction mechanism (KM) is determined in the following order:

the zero readings are set on the scale of the antimagnetic installation and the correction mechanism (KM);

the course readings are taken according to the KM scale with turning of the antimagnetic installation to courses 90, 180 and 270° and determining the corrections for each course;

the sum of corrections on the basic courses is divided by four and the mean error of teletransmission is determined;

zero reading on the diamagnetic device is corrected by the magnitude of mean error, and course "0" is set on the navigator's indicator (USh).

After computing the mean error the diamagnetic installation is successively set to courses 15, 30, 45 etc. to 345° and by a gauge the course readings on the USh are brought respectively to 15, 30, 45 etc. to 345° with the rapid adjustment knob pressed.

b) On aircraft equipped with distant-reading magnetic compass, which has PDK-3 type sensor:

Instrument errors are compensated by turning the magnetic system of the PDK-3 sensor through 15° according to the scale of the sensor. The magnetic system is turned without removal of the sensor with the aid of any magnetic bar;

with divergences in the readings of the UShM with course readings according to the scale of the PDK-3 sensor it is necessary with the gauge to bring the course readings to the UShM to the course readings according to the PDK-3 scale.

Compensation of radio deviation. The deviation of the radio compass is compensated by a mechanical compensator, installed on the axis of rotation of the closed antenna.

The guide band through a special transmission creates additional turning of the axis of the selsyn transmitter. With the aid of 24 compensating screws the guide band is given the form necessary for the readings of the radio compass every 15° of the scale (from 0 to 360°).

Before beginning the determination of radio deviation the compensator should be neutralized, having unscrewed every screw so that the guide band would acquire annular shape (additional turning of the axis of the selsyn transmitter at all course angles is equal to zero).

For determining the radio deviation it is recommended to select a radio station at a distance of 50-60 km. After determining and eliminating the adjustment error at radio compass readings (ORK) 0 and 180°, by rotating the aircraft and stopping it at ORK, multiples of 15°, the readings should be taken. At every reading of ORK there is determined the actual course angle of the radio station and the radio deviation is recorded

[Translator's note. KUR = radio station angle of approach.]

Then a chart of the radio deviation is constructed, whereupon for the avoidance of sharp deflections of the band the extremal values of the chart are divided into three equal parts and two intermediate charts of radio deviation are constructed. After this the compensator is removed from the axle of the frame and by rotation of the appropriate screws the radio deviation is compensated on the first intermediate chart, by reading the correction introduced for the given ORK on a special pointer on the compensator. Having compensated the radio deviation according to the second intermediate chart, we finally compensate it according to the radio deviation curve.

The compensation of radio deviation according to all three charts should be performed in such a sequence, so that after the introduction of each positive correction the same negative value would be introduced, i.e., as if according to a mirror reflection of the course angles.

The overall sequence of compensation is the following:  $0^\circ$ ,  $15^\circ$ ,  $30^\circ$ ,  $330^\circ$ ,  $45^\circ$ ,  $315^\circ$ ,  $60^\circ$ ,  $300^\circ$ ,  $75^\circ$ ,  $285^\circ$ ,  $90^\circ$ ,  $270^\circ$ ,  $105^\circ$ ,  $255^\circ$ ,  $120^\circ$ ,  $240^\circ$ ,  $135^\circ$ ,  $225^\circ$ ,  $150^\circ$ ,  $210^\circ$ ,  $165^\circ$ ,  $195^\circ$  and  $180^\circ$ .

After the compensation of radio deviation the compensator is installed on the frame mechanism and, by rotating the aircraft, the correctness of the performed work is checked. If inaccuracy is detected, compensation of the radio deviation is performed by additional rotation of the screws at the appropriate ORK.

The determination of the radio deviation on the ground is inadmissible on aircraft the closed antenna of ARK (Automatic Radio Compass) of which is installed in the bottom of the fuselage. This is explained by the distortion of the electromagnetic field

by electromagnetic waves, reflectent from the earth's surface. In such cases radio deviation is determined in flight, selecting for this purpose a radio station 200-300 km distant from the region of flights.

Figure 43 shows that the aircraft, performing such a flight, should intersect the assigned bearing at every reading of the course angle of the radio station. It is convenient to use such an order of course angles in flight, which has been indicated for the compensation of radio deviation on the compensating mechanism, whereupon up to KUR 270-90° the aircraft approaches the radio station, and then withdraws from it.

For reduction of time it is possible to perform flight along a 24-angle route, i.e., in practice along a circumference passing 20-30 to straight flight at each reading of the radio compass and course. One should remember that here at each reading mark it is necessary to determine the MS (aircraft position) and to plot it on a map for calculation when processing the data of the bearing of the radio station from the point of taking the reading.



With both methods the actual course angle of the radio station at the moment of taking the reading is determined by formula

$$KUR = IPR - IK^*,$$

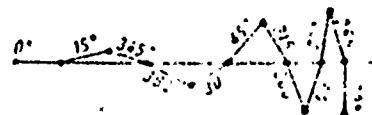


Fig. 43. Determining the radio deviation in flight.

\*[Translator's note: IPR = true bearing of a radio station; IK = true course.]

and radio deviation - by formula

$$\Delta_p = KUR - ORK.$$

The compensation of radio deviation is accomplished after landing in the same order as during its determination on the ground, but without checking the accuracy of accomplishing of works, since a repeated flight would be required.

On each aircraft there is a standard radio deviation chart, if necessary applied to the curve template of the frame.

#### DISTINCTIVE FEATURES OF THE USE OF RADIO COMPASSES DURING FLIGHTS AT HIGH ALTITUDES AND SPEEDS

The use of radio compasses in flight at high speeds with observance of all rules, imposed on the accuracy of direction finding, requires a considerable increase in the effectiveness of navigational calculations. Since these calculations are laborious, a decrease of the time by their accomplishment is very undesirable. However, this deficiency to a certain extent is eliminated by the use of ARK with pushbutton switching and combined direction finding indicators, especially with the orthodromic reference system of aircraft courses.

Another essential deficiency of the radio compasses, which operate on medium and short waves, during flights at high speeds is electrostatic interference. Despite the protection of the open antennas of radio compasses and the use of special devices for the runoff of static electricity, accumulated in pointed parts of the aircraft, during flights in clouds and precipitation there are created considerable interferences to reception in frequency range of operation of the radio compasses.

The accuracy of operation of radio compasses, especially the

accuracy of determining the flight of RNT (radio check point), negatively affects the high altitude of flight. This occurs as a result of change of the character of radio deviation at various inclination angles of the vector of propagation of radio waves, changing in large limits as the aircraft approaches the RNT. As the aircraft approaches the radio station the polarization of electromagnetic waves changes from vertical to horizontal, and then after flight over the RNT again to vertical, but opposite in phase (Fig. 44). It is obvious that antenna 1, that inclination back, will have zero reception. Further reception increases, but in the phase opposite reception up to point 1' this will involve turning of the frame of the ARK 180° up to the moment of flight over the RNT. After the flight past RNT the phase of the closed antenna will be changed, and at point 1 the open antenna. Consequently, here there will take place premature marking of the flight past RNT with subsequent (up to point 1') fluctuations of the pointer.

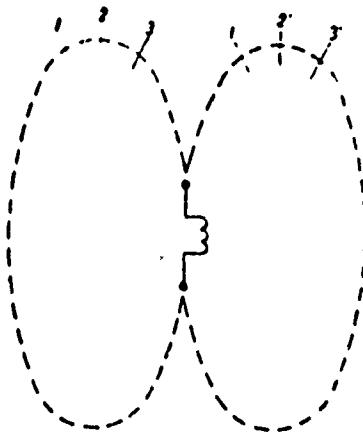


Fig. 44. The polarization of electromagnetic waves during flight past the radio station.

If the antenna has been tilted forward (position 3), then fluctuations of the ARK pointer will begin at point 3, the flight past the radio station and the rotation of the pointer to 180° will be noted with delay (at point 3').

With strictly vertical position of the antenna (position 2)

there is possible premature rotation of the ARK pointer  $180^\circ$ , whereupon the pointer can rotate in the opposite direction and for the second time note the flight past RNT at point 2'.

The artificial open antenna of the radio compass in the relationship to its slope in vertical plane - resultant, which connects the upper or lower point of the antenna with the electrical center, i.e., with its grounding or counterweight (Fig. 45).

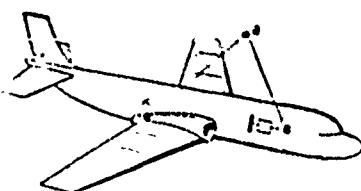


Fig. 45. The influence of the equivalent of the open antenna on the mark of the flight past the radio station: a) top point of antenna; b) electrical center of the aircraft; c) receiver.

It is natural that straight line a-b, being the equivalent of the antenna inclination (in our case - forward - with installation of the antenna above the fuselage), will cause delay in marking the moment of flight over the RNT.

If the antenna is installed at the same distance from the electrical center, but under the fuselage, then the marking of the moment of flight past the radio station is premature. With arrangement of the antenna behind the electrical center of the aircraft the picture will be the opposite.

It is obvious that the location of the antenna directly above or below the electrical center of the aircraft is more suitable, but here there is possible an advance or delay of the fly-by marks, and also the appearance of double fly-by marks, since in practice errors depend not only on the altitude and speed of flight, but also on the angle of pitch, the accuracy of flight of the aircraft over the radio station, etc. In practice precise flight past is extremely rare and there occurs combination of the

effect of crossing with the effect of following (determination of the passage of the traverse of RNT).

On the various types of aircraft during flights at different altitudes and speeds the errors of the crossing of the pointer to 180° lie within from 1 to 3 flight altitudes.

Precise tracking is possible only with comparatively considerable deviations of the aircraft from the radio station during flight. This distance exceeds the flight altitude and is located beyond the zone with horizontal polarization of electromagnetic waves.

#### COURSE SYSTEMS

The assembly of the course systems is given in Table 20.

Table 20. The assembly of course systems

Name	The quantity of units on the aircraft, pieces.			
	Tu-114	Il-18	An-10	Tu-124
Course system (Brand)	KS-5	KS-6	KS-6	KS-10
Inductance pickup ID-2	2	1	1	1
Gyro unit GA-1T or GA-1P	2	2	2	2
Control panel PU-1	2	1	1	1
Relay unit BR-1	1	1	1	1
Correction mechanism KM-4	2	1	1	1
Navigator's indicator USh	1	1	1	1
Pilot indicator UK	-	1-2	2	2
UGA-IV indicator	1	1	1	1
UGR-IV indicator	2	-	2	1
UGPK indicator	-	0-1	0-1	-
Amplifier U-11	1	1	1	1
Amplifier U-14	1	-	-	-

It is necessary to remember that with use of system in the "GPK" (directional gyroscope) mode aboard the aircraft there are the following duplicate readings:

a) on the UGA-1U indicator:

on pointer "G" - the gyromagnetic course, obtained from the second gyro unit;

on pointer "A" - the true or orthodromic course, obtained from the astrocompass;

b) on readings of the scale of KM-4 correction mechanism - magnetic course (taking into account instrument error).

The main malfunctions of the course systems and the methods of their elimination are given in Table 21.

Table 21. The basic malfunctions of course systems.

Malfunction	The cause and method of elimination in flight
in mode "MK" and "GPK" on the KM-4 the MK remains unchanged with change of the course.	Failure of ID-2 or U-11 (on channel ID-2-KM-4). With failure of ID-2 it is necessary to change to operation of KS in the "GPK" mode with periodic astro-correction and, having corrected the spare gyro-unit to the main, compare in flight the reading of the "G" pointer of the UGA with readings of USh.
In the "GPK" mode the readings of USh and UK are unchanged or during the check of OK divergences are noticed.	Failure of the gyro unit (main or spare). If the same defects are observed on the "G" pointer of UGA-IV, then, besides the failure of GA-1, there can be failure of amplifier U-11 (KM-4-GA-1). One should change to the spare gyro-unit with periodic magnetic correction or astrocorrection.
Incorrect readings of KS after banks	Failure of TsGV, and after the turn of VK-53-RB. It is necessary to switch the KS over to communication with the spare vertical gyroscope or set the appropriate switch to the operating position without the vertical gyroscope.
The absence of readings on UK with their presence on USh.	Burnt-out fuse in BR-1-PK-30 at 0.15 a.

AIR NAVIGATION BY THE GREAT CIRCLE  
WITH THE USE OF COURSE SYSTEMS, HOMING  
STATIONS, RADIO BROADCASTING STATIONS  
(RVS) AND RADAR REFERENCE POINTS

The preparation of a map for flight along orthodromic track. On maps utilized for flights in civil aviation (scale 1:1,000,000 and 1:2,000,000), the great circle with length 1000-1200 km in practice is a straight line. This makes it possible on the maps to plot the orthodromes of sections graphically (with the aid of a rule) without calculations of intermediate points by formulas. To the same track length it is possible to execute flight with orthodromic track angle from one reference meridian of the section.

The following system of plotting of orthodromic track angles on a flight map is recommended. If the flight route has not been laid on the orthodrome, i.e., it should pass through certain prescribed points, then it is divided into separate sections, the length of which along the orthodrome should not exceed 1000-1200 km. In this case it is desirable that the starting points of the section would coincide with the route turning points (PPM). The division of the route not at points of the PPM is allowed only with large length of the straight portions of the track.

The meridians of the starting points of the orthodrome of the section are considered reference meridians for the measurement of track angles. The great circle track angle from the first reference meridian to the first PPM is measured directly from the reference meridian. The track angles to the next PPM are determined as the sum of the first track angle with the angle of turn of the track at the first PPM (Fig. 29):

$$\text{OTN}_2 = \text{OTN}_1 + \text{YP} \quad \text{etc.}^*$$

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\*[Translator's note. OTN = OPU = great circle track angle, YP = UR = angle of turn.]

Example.  $OPU_1 = 60^\circ$ ,  $UR = 30^\circ$ ,  $OUP_2 = 60^\circ + 30^\circ = 90^\circ$ .

With the number of PPM more than three to avoid the accumulation of errors of the second and subsequent OPU by summation of the azimuth we determine the great circles of the section with angles of intersection of the assigned track and the great circle of the section (see Fig. 30):

$$OPU = A + UP.$$

For example.  $A = 130^\circ$ ;  $UP = -30^\circ$ .  $OPU = 130^\circ - 30^\circ = 100^\circ$ .

Furthermore, the OPU can be measured directly on the map from any meridian with subsequent introduction of correction to the angle of convergence of the reference meridian and the meridian of the place of angle measurement:

$$OPU = IPU \pm \delta.$$

For return flight the track angles are plotted from the reference meridians, which are final during flight in the initial direction. Therefore, the track angles of the reverse direction will be  $180^\circ$  different from the initial direction plus the correction for the convergence of meridians.

If the entire flight route passes along the great circle and does not have PPM, then the plotting of track angles is considerably simplified. In this case the route should be divided into orthodromic sections 1000-1200 km long. The meridians of the initial points of the section are considered reference meridians during the calculation of great circle track angles for forward and reverse direction; from these meridians the great circle track angles are measured.

The marking of the route for flights with great circle track angles is performed the same as for flight with magnetic loxodromic track angles. The track is divided into segments 50 km each

with numbering every 100 km. To the right of each section between PPM there will be placed a line, above which is indicated the distance between PPM, and under the line - the preset time of flight on the section. More to the right of the line is written the OPU.

The general sequence of preparation of the map for flight along the orthodromic track is recommended the following:

1. Regardless of the presence of salient points connect by a straight line on the map the section of route with length 1200 m. The straight line laid on the map will be the great circle of the section. In the future all calculations of track angles should be performed from this line.
2. Measure on the map with a protractor the azimuth of the great circle on the meridian passing through the starting point of the section.
3. Construct the assigned track on the map. For this by straight lines connect the route turning points.
4. For each segment of the assigned track calculate the great circle track angle. This angle for each segment, except the first, is measured and calculated from the azimuth of the great circle of the section, from the first great circle track angle or from any meridian taking into account the correction for convergence of meridians.
5. Write the great circle track angles on the map to the right of the route.
6. Designate the reference meridians of each section on the map with the color red.

7. At each meridian to the right of the route plot the amount of correction for convergence of the given and reference meridians and magnetic declination. During flight to the east the correction is written with the "minus" sign, in flight to the west - with the "plus" sign. The written corrections for convergence of the given and reference meridians are used during calculation and plotting of the actual track and radio bearings on the map, where corrections are considered with their sign.

8. For the case of necessity of changing from orthodromic calculation to flight with magnetic track angles there is compiled a table of magnetic track angles to the route segments of such extent, so that the MPU of adjacent segments would be not more than 3-4° different.

**The execution of flight.** Flight along the great circle track using gyroscopic course instruments, including the GPK-52, is accomplished by the following scheme, which remains identical for all orthodromic sections:

1. Before flight past the reference meridian at 20-30 km adjust the KS. Set the initial data on the KS, GPK, NI-50, DAK-DB-5.

2. During flight past the reference meridian set the aircraft according to the USh on the calculated orthodromic course, check the correctness of the taken course by all the duplicate course instruments.

3. Following the orthodromic track.

4. Correction of gyro unit of KS and GPK-52.

5. Monitoring and correction of path.

6. Approach to the reference meridian of the route turning point.

If the orthodromic section has salient points of the path, i.e., the route turning points, then at these points it is necessary to set the aircraft by the GPK to the appropriate course, which just as the azimuth of the great circle of the section is read from the reference meridian.

In accordance with this general scheme the procedure and sequence of accomplishing flight on each orthodromic section consist of the following:

1. All course instruments must be activated on the ground after starting the engines. After the warming up of instruments and step up of the gyrorotors on the control panels of the GPK-52 and KS set the rounded off value of the latitude  $\phi$  of the starting point of the section.

For example, if the latitude of the starting point of the section is  $53^{\circ}32'$ , then one should set latitude  $54^{\circ}$ .

On the DAK-DB set: the latitude and longitude of the starting point of the section, the declination and Greenwich hour angle of the Sun, and also release the sweep to zero and set the calculated ground speed on the course adjuster.

On the scale of declinations set the declination of the starting point of the orthodromic section.

2. With intersection of the reference meridian of the section set the aircraft on the calculated true course, equal to the track angle of the assigned great circle with correction for the drift angle. By strictly holding this course, set the

GPK-52 to the reading which corresponds to the true course, switch the KS to the "GPK" operating mode.

3. By performing flight by the GPK with the predetermined heading, determine the drift angle and introduce the correction to the predetermined course.

4. For approach to the next given track angle turn the aircraft according to the GPK to the right or left to the new predetermined heading.

When accomplishing flight on high-speed aircraft it is necessary to begin the turn for approach to the next assigned course angle before flight past the PPM in accordance with the precalculated linear turn lead (LUR).

5. Having set the aircraft according to the GPK to the course equal to the new assigned track angle of the great circle with drift correction, execute flight with this heading to the next turning point, while refining the amount of the taken correction.

6. With change of the latitude  $\phi$  of the aircraft position to a magnitude equal to the next nearest value of "latitude" scale division, on the control panels of GPK-52 and KS set the new value of latitude<sup>1</sup>.

7. While performing flight according to the GPK with predetermined headings, periodically monitor the readings of the GPK by the following methods:

<sup>1</sup>It is admissible when accomplishing flights to set the latitude control point adjuster to the middle latitude of the orthodromic section, if the difference of latitudes in high latitudes does not exceed  $10^\circ$ , and in low  $-5^\circ$ .

a) by comparison of the magnetic course of the aircraft according to the magnetic compass with the true orthodromic course on the GPK. At each separate moment the magnetic course on the magnetic compass should be different from the orthodromic course on the GPK by the sum of corrections for the angle of convergence of the reference meridian, meridian of the aircraft position and magnetic declination MS:

$$OK = MK + (\lambda_{o.M} - \lambda_{M}) \sin \phi_{cp} / \Delta_M$$

where MK - magnetic course of the aircraft; OK - orthodromic course of the aircraft according to the GPK, read from the reference meridian of the orthodromic section;  $\lambda_{o.M}$  - longitude of reference meridian;  $\Delta_M$  - magnetic declination MS;  $\phi_{cp}$  - middle latitude.

For the convenience of comparison of the readings of the GPK and magnetic compass it is advantageous to set this total correction on the scale of declinations of the USh, whereupon the readings of these instruments should coincide with limits of the accuracy of their operation. In course systems this total correction can be added to the readings of the magnetic course on the UGA, i.e.,  $OK = MK + \Delta$ , compare the obtained result with readings of USh (working in "GPK" mode). In the case of divergence of readings introduce correction;

b) by comparison of the orthodromic course on the astro-compass with the orthodromic course on the GPK. At each separate moment these readings should coincide within the accuracy of operation of the instruments.

8. Periodically every 10-15 min of flight determine the drift angle and according to the findings refine the heading.

9. For providing the most precise approach of the aircraft to the starting point of the next orthodromic section perform dead

reckoning and periodically determine the calculated aircraft position.

During flight by the GPK with orthodromic course, calculated from the reference meridian of the orthodromic section, the calculation and plotting of the radio bearings of the aircraft on the map must be performed in the following order:

- a) with the aid of ARK or airborne radar determine the radio station or reference point angle of approach (KUR, KUO);
- b) determine the orthodromic heading of the RNT or reference point as the sum of the orthodromic course (OK) by the GPK and the heading (KUR) (KUO):  $OrR = OK + KUR (KUO)$ ;
- c) for plotting the true radio bearing on the map from the meridian of the RNT or reference point determine the aircraft true bearing, considering the correction for the angle of convergence of the reference meridian of the orthodromic section and the meridian of the radio station or reference point

$$IPS = OPR - (\lambda_{o.m} - \lambda_p) \sin \phi_{cp} \pm 180^\circ$$

where  $\lambda_p$  - longitude of the radio station or reference point;  $\lambda_{o.m}$  - longitude of the reference meridian;  $\phi_{cp}$  - middle latitude.

In practice the aircraft true bearing can be determined in the following manner:

- a) take from the map the correction for the angle of convergence of the meridian of the RNT (reference point) and reference meridian;
- b) on the course scale of ARK or radar indicator set the true course as the sum of the orthodromic course and the correction for the convergence of meridians taken from the map;

c) read the aircraft true bearing by the position of the ARK pointer or the crosshair of the radar indicator.

When using the KS for radio direction finding of the system the orthodromic bearing of the aircraft is read directly by the position of the ARK pointer (opposite end), and to obtain the aircraft true bearing the correction for the angle of convergence of the meridian of the radio station and reference meridian, taken from the map, is considered with its sign;

d) plot the calculated aircraft true bearing on the map with the aid of a protractor, having applied it on the meridian, passing through the radio station (Fig. 46).

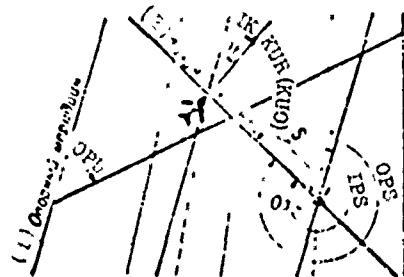


Fig. 46. Plotting of calculated IPS.  
KEY: (1) Reference meridian; (2) Line of bearing.

10. Approach the starting point of the next orthodromic section.

11. Set the aircraft on course by the UShA, being monitored by astro or magnetic compass. Set the GPK to the reading which corresponds to the MK in flight along OMPU; and in flight along OPU - to magnitude  $MK + \Delta_{\text{I.I.Q.M.}}$ .

12. Subsequently perform flight in the same sequence as shown above in pp. 3-10.

On aircraft with course systems the autonavigator of the NI-50BM ground-position indicator is included in the USh of the

KS. Therefore, on these aircraft the gravitation on the autonavigator and wind reference input element NI-50 is set equal to the great circle track angle and dead reckoning with respect to range and lateral deviation is performed relative to the assigned orthodromic track.

On aircraft with off-line operation of course instruments, where the autonavigator NI-50 is connected to the USh of magnetic distant-reading compass, the dead reckoning on the coordinator will be performed from the magnetic course. Since actually flight will be accomplished with constant orthodromic course, and the readings of the magnetic compass will be continuously changed, in dead reckoning with respect to the direction errors will arise, since integration of the path will be fulfilled by the curve, convex in the direction opposite the magnetic rhumbline (Fig. 47).

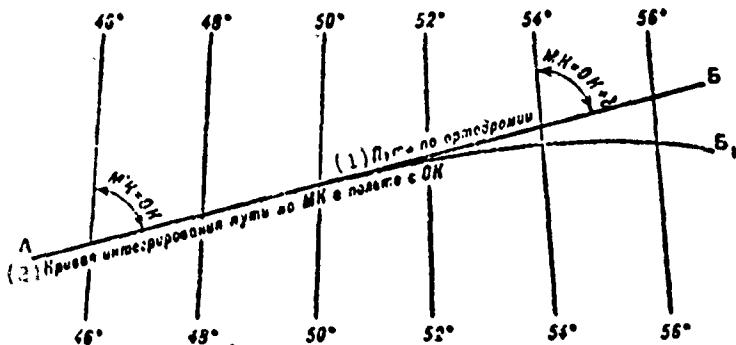


Fig. 47. Route along great circle and the integration curve of the route.

KEY: (1) Route along great circle; (2) Integration curve of route to MK in flight from the OK.

In order that the NI-50 readings could be used for monitoring the path with respect to direction, for example, for the measurement of speed and wind direction at flight altitude, the gravitation of NI-50 must be set equal to the OPU, and to readings of the magnetic compass periodically every 100-150 km of the route introduce total correction  $\Delta$ :

$$\Delta = \Delta_M + (\lambda_{OM} - \lambda_{MC}) \sin \varphi_{cp}.$$

This total correction to the readings of the magnetic compass is introduced with the aid of the declination scale of the USh.

#### SYSTEM OF READING OF TRACK ANGLES AND COURSE OF THE AIRCRAFT

The selection of the system of reading the track angles of flight and the aircraft course depends upon the operating data of the aircraft and its navigation equipment.

The conditions of the use of course instruments on the aircraft can be divided into three groups:

1. Flights with small limits of change of magnetic latitudes on aircraft equipped with magnetic or gyromagnetic compasses.

2. Flights with considerable changes of magnetic latitudes on aircraft equipped with magnetic compasses, directional gyroscopes or course systems of average accuracy, without automatic measurement of drift angle, ground speed and dead reckoning.

3. Flights to any distances on aircraft equipped with precise course systems and instruments for automatic measurement of drift angle, ground speed and dead reckoning.

For the first group of conditions we select the magnetic loxodromic system of reading the track angles of flight and the aircraft course. In this case the length of each loxodromic route segment is taken so that the magnetic track angle at its starting point would be different from the track angle of the terminal point by not more than  $2^\circ$  with length of segment up to 300 km, i.e.,

$$(0_{\text{final}} - \lambda_{\text{initial}}) \sin \varphi_{\text{CP}} - \\ - (\Delta \lambda_{\text{final}} - \Delta \lambda_{\text{initial}}) \cdot 2^\circ,$$

where  $\lambda_{\text{ нач }}, \lambda_{\text{ кон }},$  - the longitudes of the initial and terminal point of the route segment;  $\Delta_{M_{\text{ нач }}}^{\text{ нач }}, \Delta_{M_{\text{ кон }}}^{\text{ кон }},$  - the magnetic declination of the initial and terminal point;  $\phi_{\text{ cp }}$  - the middle latitude of the segment.

In this case the mean magnetic track angle of the segment differs from the extreme by not more than  $1^{\circ}$ , and the maximum deviation of the loxodromic track from the orthodromic does not exceed values

$$z = \frac{s}{2} \operatorname{tg} 0^{\circ} 5.$$

i.e., the loxodromic line coincides with the orthodromic (Fig. 48).

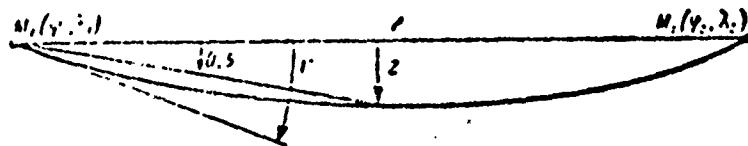


Fig. 48. Magnetic loxodromic course angle.

If the initial and final track angles of the segment differ by less than  $2^{\circ}$ , then the length of the loxodromic route segment can be increased during flights in meridional direction or in any direction in the equatorial latitudes with small changes of  $\Delta_M$ .

The magnetic loxodromic course angle in the practice of air navigation is usually called the magnetic course angle (MPU).

The MPU is measured relative to the magnetic meridian of the midpoint of the route segment:

$$\text{MPU} = \text{IPU}_{\text{cp}} - \Delta_{M_{\text{ cp }}},$$

where  $\text{IPU}_{\text{cp}}$  - the direction of the track of the relative true meridian of the midpoint;  $\Delta_{M_{\text{ cp }}}^{\text{ cp }}$  - magnetic declination at the midpoint of the track.

More accurately the MPU can be determined by measurement of directions at the beginning and end of the track:

$$MPU = \frac{IPU_{H\dot{A}4} + IPU_{KOH} - (\Delta_{M_{H\dot{A}4}} + \Delta_{M_{KOH}})}{2},$$

since in this case the averaging of two measurements occurs, which decreases their error.

Example of determining the MPU of the route segment.

Given:  $IPU_{H\dot{A}4} = 470^\circ$ ;  $\Delta_{M_{H\dot{A}4}} = +5^\circ$ ;  $IPU_{KOH} = 49^\circ$ ;  $\Delta_{M_{KOH}} = +3^\circ$ .

Solution:

$$MPU = \frac{47 + 49 - (5 + 3)}{2} = 44^\circ.$$

For the second group of conditions we select the orthodromic system of reading track angles of flight and aircraft courses relative to the reference meridians or the zero meridians of the route segments. In this case the great circle track angle of flight (OPU) is considered equal to the true track angle of the route segment at its starting point or at the point of intersection of the continuation of the segment with the reference meridian (Fig. 49).

During flight past reference meridians or the initial points of the route segments the directional gyroscope or course system displays readings of the true course of the aircraft. For example, the course system is transferred to the MK mode with the setting (on the declination scale) of magnetic declination at point MS or to the astronomical correction mode. After matching (final adjustment of true course) the system is transferred to the GPK mode.

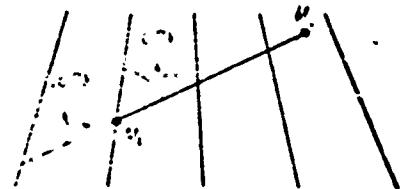


Fig. 49. Selection of OPU.

If it is necessary to check the accuracy of readings of the orthodromic course at any other point, then the readings of the GPK compare with the readings of the astrocompass, at this there should be fulfilled equality (under the condition that DAK-DB-5 issues not orthodromic AK, but the IK of the aircraft position)

$$OK = IK + (\lambda_{0.M} - \lambda) \sin \varphi_{cp},$$

where OK - orthodromic course; IK - reading of astrosensor;  $\lambda_{0.M}$  - the longitude of the reference meridian or meridian of the initial point of the route segment;  $\lambda$  - current longitude of MS;  $\varphi_{cp}$  - middle latitude between the point of display of orthodromic course and MS.

The accuracy of readings of the orthodromic course can also be checked by readings of the magnetic compass with the introduction into them of total correction

$$\Delta = (\lambda_{0.M} - \lambda) \sin \varphi_{cp} + \Delta_M + \Delta_K,$$

where  $\Delta_M$  - magnetic declination MS;  $\Delta_K$  - magnetic compass deviation. Then  $OK = KK + \Delta$ .

If the indicated conditions are not observed, then correction is introduced to the readings of GPK, equalizing the left side of the equation with the right.

Example  $\lambda_{0.M} = 44^\circ$ ;  $\varphi_{cp} = 56^\circ$ ;  $\lambda = 58^\circ$ ;  $\Delta_M = -6^\circ$ ;  $\Delta_K = +2^\circ$ ;  $OK = 52^\circ$ ;  $KK = 70^\circ$ .

Determine the orthodromic course error.

Solution:

$$\begin{aligned}\Delta_{OK} &= KK \div (\lambda_{0, \text{sp}} \lambda) \sin \varphi_{\text{sp}} - \Delta_{\text{u}} - \\ &\div \Delta_K - OK = 70 \div (44 - 38) 0,8 - \\ &- 6 \div 2 - 52 = 3^\circ.\end{aligned}$$

Conditions of the second group suppose flights with large changes of magnetic latitudes. Therefore, in conducting the deviational operations it is necessary to determine on the aircraft the coefficients of semicircular deviation of magnetic sensor B and C:

$$\begin{aligned}B &= \frac{\sum_{i=0}^{7.0} A_{ki} \sin i}{4} ; \\ C &= \frac{\sum_{i=0}^{7.0} A_{ki} \cos i}{4} .\end{aligned}$$

where  $i = 0,45, 90, \dots, 315^\circ$  (a total of eight rhumbs).

Since on aircraft of the indicated group the deviation is mechanically compensated to zero at the latitude of the place of its elimination, then at any other magnetic latitude

$$\Delta_K = \left( \frac{H_y}{H} - 1 \right) \times (B \sin MK + C \cos MK),$$

where  $H_y$  - the intensity of the horizontal component of the earth's field at the place of elimination of deviation;  $H$  - the intensity of the horizontal component of field at point MS.

For the third group of conditions we also select the orthodromic system of reading the track angles of flight and aircraft course. However, taking into account the high requirements for the accuracy of measurement of the course for automatic dead reckoning and the operational stability of the course system in the "GPK" mode, we try to retain and more precisely determine the established course reading system at the departure point over the entire length of the flight route.

The most convenient and precise method of determining the elements of the great circle and of flight along orthodromic route segments is the following. For each orthodromic segment we determine the displacement of longitudes  $\lambda_{\text{смеш}}$  for the transition from longitude  $\lambda$  to longitude  $\lambda_0$ , read from the point of intersection of the great circle with the equator (Fig. 50).

For point  $M_1$   $\lambda_{\text{смеш}} = \lambda_{0_1} - \lambda_1$ ,

where  $\text{ctg} \lambda_{0_1} = \text{tg} \varphi; \text{ctg} \varphi; \text{cosec} \Delta \lambda - \text{ctg} \Delta \lambda$ ,  
then the current longitude of any point of the segment will be equal to

$$\lambda_0 = \lambda + \lambda_{\text{смеш}}$$

All elements of the great circle are easily determined if the longitude of its points is read from the point of intersection of the great circle with the equator:

the initial azimuth at the point of intersection with the equator  $\text{tg} \sigma_0 = \frac{\sin \lambda_0}{\sin \varphi}$ ; current azimuth  $\text{tg} \sigma = \frac{\text{tg} \lambda_0}{\sin \varphi}$ ; intermediate points sign  $\lambda_0 = \text{tg} \sigma_0 \text{tg} \phi$ ;

great-circle distance from the point of intersection with the equator

$$\cos S_0 = \cos \lambda_0 \cos \varphi;$$

the distance between two points

$$S_{x_1, y_1} = S_{0_1} - S_{0_0}.$$

As the great circle track angle of the first route segment we take its azimuth at the departure point of the aircraft.

The track angles of all subsequent route segments are obtained by summation of the track angles of the previous sections with the

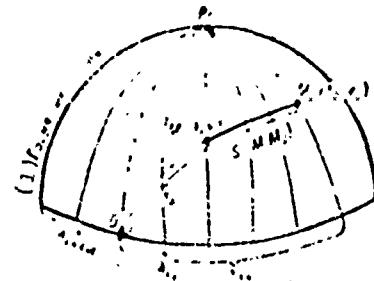


Fig. 50. Displacement of longitudes.

KEY: (1) Greenwich meridian.

angle of turn of the track for flight along the next section (Fig. 51). In this case the angle of turn is defined as the difference of azimuths of the route segments at the point of their intersection, obtained by using formula

$$\operatorname{tg} \alpha = \frac{\operatorname{tg} \lambda_0}{\sin \varphi}, \text{ i.e.}$$

$$UP = \operatorname{arctg} \frac{\operatorname{tg} \lambda_{0_2}}{\sin \varphi} - \operatorname{arctg} \frac{\operatorname{tg} \lambda_{0_1}}{\sin \varphi},$$

where  $\lambda_{0_2} = \lambda + \lambda_{\text{смеш}_2}$ ;  $\lambda_{0_1} = \lambda + \lambda_{\text{смеш}_1}$ , at the point of intersection of the path sections.

The more accurate determination of the orthodromic course in flight is fulfilled through the appearing lateral deviations of the aircraft from the specified track at the correction points of the aircraft coordinates.

$$\Delta_{OK} = \operatorname{arctg} \frac{\Delta_z}{S},$$

where  $\Delta_z$  - error in dead reckoning  $S$  in terms of direction;  $S$  - path of the aircraft between the correction points of coordinates.

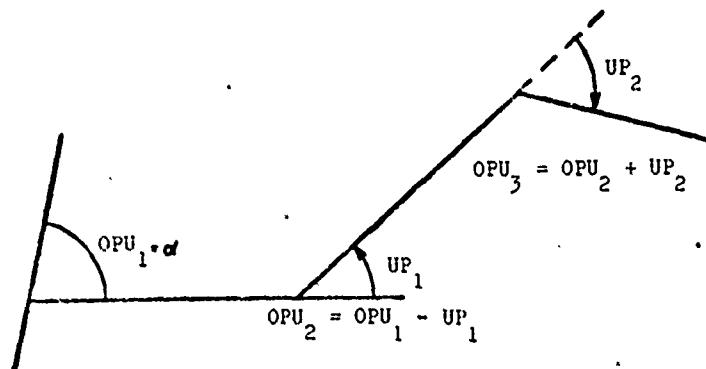


Fig. 51. Track angles and turning angles.

The correction introduced in this way is common for course, drift angle and dead reckoning, which is especially advantageous for air navigation.

With the correction of the orthodromic course by an astro-compass it is necessary that the following condition be observed

$$OK - AK = OPU \operatorname{arctg} \frac{\operatorname{tg} \lambda_0}{\sin \varphi},$$

with correction by magnetic compass this condition assumes the form

$$OK - KK = OPU - \operatorname{arctg} \frac{\operatorname{tg} \lambda_0}{\sin \varphi} + \Delta_m + \Delta_n.$$

If these conditions are not fulfilled, then to the OK readings a correction is introduced which equalizes the left side of the equation with the right.

The account of the magnetic compass deviation for the third group of conditions is conducted by the rules accepted for the second group.

Taking into account the high accuracy of course instruments both for the third and for the second groups, depending on the concrete flight conditions, the use of orthodromic reading of the track angles from magnetic reference meridians is possible.

#### FEATURES OF READING THE GREAT CIRCLE TRACK ANGLES DURING FLIGHTS IN THE CENTRAL ARCTIC

For air navigation in the Central Arctic the following features are characteristic:

large angles of convergence of meridians, involving a rapid change of the current longitude, particularly with directions of routes close to  $90^\circ$  ( $270^\circ$ );

considerable distances from the pole to the coast of the USSR, and also Alaska, Canada and Greenland.

The large angles of convergence of meridians in many route flights in the Central Arctic force the rejection of flights along rhumb line and the transfer to flights along a great circle. In this case the calculation of directions is performed from one constant meridian, in this case called conditional meridian.

The accomplishing of flights along a rhumb line in high latitudes is connected with great inconveniences for the following reasons:

the large curvature of rhumb line, with the exception of flights with courses close to  $0^\circ$  ( $180^\circ$ ), requires the continuous turning of the aircraft in horizontal plane. In this case the turns cause accelerations, which affect the accuracy of operation of the navigational instruments, which have pendulum (bubble) vertical line or correction (aircraft sextants, gyro horizons and others). The angular velocity of the aircraft in horizontal plane in proportion to approach to the pole considerably increases and is characterized by the following values, expressed in degrees after 1 min. of flight (Table 22);

the use of magnetic compasses in high latitudes is limited, and at values of horizontal component 0.05-0.06 oersted become unreliable;

the percentage elongation of the loxodromic path as compared with the orthodromic at latitude  $75^\circ$  is 55%, and to the north - it increases still more.

Table 22. Variation of angular velocity in flight to the pole.

Latitude, deg	Angular velocity, °/min	
	v. 100 km/h	v. 120 km/h
60	0.1	0.2
75	0.2	0.4
80	0.3	0.6
85	0.6	1.2
88	1.5	3.0

For the indicated reasons it is better to perform route flights in high latitudes along the great circle. For this very reason for such flights the astrocompass and directional gyroscope appeared for the first time and were widely applied as the main great circle course instruments.

However, it proves to be a sufficiently complex problem to maintain in flight a path along the great circle, because the course (track angle) along the great circle in high latitudes is changed from meridian to meridian by approximately the magnitude of the angle of convergence between these meridians (Fig. 52).

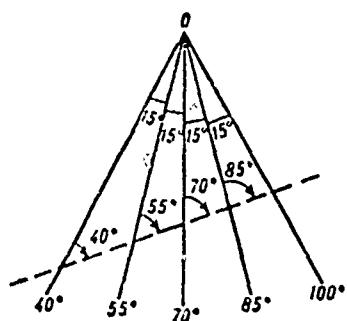


Fig. 52. The measurement of track angles along great circle route.

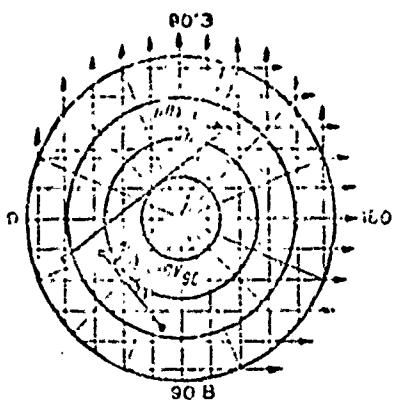
In practice we go to simplifications, knowingly allowing some errors. For example, on the astrocompass or directional gyroscope we maintain not the actual orthodromic course relative to each of the meridians, but the mean orthodromic course relative to the mean meridian of the section of the route; the mean meridian in this case is the conditional meridian, relative to which the astrocompass or directional gyroscope shows the course.

In the majority of cases, and in the polar basin of the Arctic in all cases the route plotting and navigational calculations can be performed without considerable errors relative to one of the two constant conditional meridians.

On many aviation maps, accepted for flights in the Arctic there are plotted two grids of mutually perpendicular parallel

lines, which depict two such constant conditional meridians - Greenwich ( $\lambda = 0$ ) and the meridian perpendicular to it ( $\lambda = 90^\circ$ ). The latter is selected because east longitude  $90^\circ$  corresponds approximately to the mean longitude of the area of the Arctic adjacent to the territory of the USSR. Figure 53 by pointers shows the direction of both meridians, taken as north, from which as from the northern tip of the geographical meridian we read clockwise all navigational directions: track angle, course, azimuth (heading), wind direction.

Fig. 53. Diagram of conditional meridians.



Directions relative to Greenwich meridian (or the meridian with  $\lambda = 90^\circ$ ) and relative to any geographical meridian are connected together by the following relationships:

$$IPU_{rp} = IPU \mp \lambda_3^B$$

$$\text{and } IPU_{90} = IPU \mp \lambda_3^B + 90^\circ;$$

$$IPU = IPU_{rp} \pm \lambda_3^B$$

$$\text{and } IPU = IPU_{90} \pm \lambda_3^B - 90^\circ,$$

where  $\lambda_3^B$  - the east or west longitude of the geographical meridian.

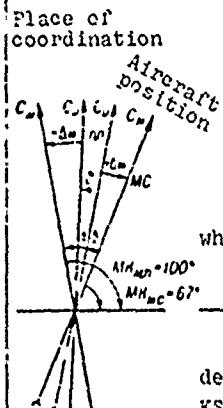
Calculation of correction to KS-6 for transfer to landing meridian.

$$MK_{n,n} = MK_{n,c} - (\pm \Delta);$$

$$\Delta = (\lambda_{n,n} - \lambda_{n,c}) \sin \varphi_{cp} - (\Delta_{n,n} - \Delta_{n,c}), \text{ or}$$

$$\Delta = \pm \Delta_{n,n} + (\pm \delta) - (\pm \Delta_{n,c}),$$

where  $\Delta_{n,n}$  - the magnetic declination of the landing point;



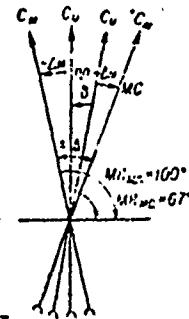
$\Delta_{n,c}$  - magnetic declination of the place of coordination;

$\delta$  - correction for the convergence of meridians.

$$\delta = (\lambda_{n,c} - \lambda_{n,n}) \sin \varphi_{cp},$$

where  $\lambda_{n,c}$  - longitude of the place of coordination.

$\lambda_{n,n}$  - longitude of the landing point.



After coordination of KS-6 before the beginning of descent in the "MK" mode it is necessary to transfer the KS-6 to the GPK mode and on the USH by the scale of declinations to set the values of  $\Delta$  with opposite sign.

Instead of the track angle in formulas there can be taken the course, azimuth (heading) or wind direction.

If it is decided to perform the route plotting and navigational calculations relative to one of these two conditional meridians, then during comparison of the readings of the magnetic compass with the readings of the astrocompass or directional gyroscope, on which  $IK_{rp}$  or  $IK_{90}$  is set, difficulties appear:

$$MK = IK + \Delta_{11} = IK_{rp} \pm \lambda_3^B - \Delta_n - MK_{90} \pm \lambda_3^B - 90^\circ - \Delta_n.$$

In order to determine what the true course is equal to relative to Greenwich meridian (or the meridian with  $\lambda = 90^\circ$ ) according to the magnetic course of the compass, it is necessary to take the value of  $\Delta_{11}$  from the map and then perform two-three arithmetic operations. The problem is solved simpler if on the map there have been plotted not the magnetic isogonic lines, but conditional isogonic lines - lines of equal angles being comprised

by the magnetic pointer with the northern direction of the conditional meridian ( $\lambda = 0^\circ$  or  $\lambda = 90^\circ$ ). When such conditional isogons, enumerated by values of  $\Delta_{n_{rp}}$  or  $\Delta_{n_{90}}$ , exist on the map the transfer from MK to  $IK_{rp}$  ( $IK_{90}$ ) and vice versa is performed with respect to relationships

$$MK = IK_{rp} - \Delta_{n_{rp}}$$

$$\text{and } MK = IK_{90} - \Delta_{n_{90}}$$

$$IK_{rp} = MK + \Delta_{n_{rp}}$$

$$\text{and } IK_{90} = MK + \Delta_{n_{90}}$$

$$MK_{nn} = MK_{mc} - (\pm \Delta);$$

The use of the map with conditional isogonic lines has one additional advantage: all the conditional isogonic lines converge only at the point of the magnetic pole (magnetic isogons converge still at the point of the geographical pole), therefore near the area of the geographical pole there is no thickening of the conditional isogonic lines and there is not need for knowledge of the MS with high accuracy in order to take the correct value of  $\Delta_{n_{rp}}$  ( $\Delta_{n_{90}}$ ) from the map.

#### NI-50 POSITION AND HOMING INDICATOR

Position and homing indicator NI-50 is the automatic dead reckoning device which operates in the orthodromic coordinate system. It serves for solution of the following problems:

determining of MS to within 3-5% of the path passed from the point of the beginning of calculation;

determination of wind speed and direction;

monitoring of the moment of approach to the reference landmark, precise determination of which is impossible by other methods;

the conducting of automatic dead reckoning during search flights;

bypass of thunderstorms and approach to LZP.

The computer of the position and homing indicator sums up the readings of the course instruments and the special airspeed transmitter, input into it with the aid of electro-induction transmission, and then "distributes" them to the components of motion of the aircraft in rectangular coordinates.

Control and indication are accomplished by a coordinate counter, wind control point adjuster and by an autonavigator.

The coordinate counter with the aid of pointers "S" and "V" continuously issues present-position data in kilometers in the form of range and lateral deviation.

The wind control point adjuster serves for considering the wind effect on the aircraft flight. The wind direction is taken navigational (where it blows to).

With the aid of the autonavigator the rectangular coordinate system is oriented by the manual introduction of the grivation. The grivation is the angle between the northern direction of the meridian and randomly taken axis X, relative to which it is proposed to measure the lateral deviation of the aircraft. As a rule, the grivation is taken equal to the track angle. During flights along large routes, which have salient points, axis X can be the mean orthodromic direction of the route.

The autonavigator can operate from the gyromagnetic compass. Then it shows the magnetic course, and the grivation is read from the magnetic meridian at the point of beginning of checking the path by the indicator.

The pointers of the coordinate counter and the grivation are reset for each section of the path.

During flight using great circle track angles, i.e., during operation of the indicator from GPK, dead reckoning can be accomplished without additional correction at the 1000-1200 km stage. In this case the course indicator shows the course from the reference meridian, and the grivation is established equal to the assigned OPU (great circle track angle).

The position of the aircraft is determined according to the readings of pointers "S" and "V" of the coordinate counter. During flight along a route with short straight sections for the origin of coordinates it is possible to take the beginning of each section. If this route is well equipped with radio aids and it is possible to exactly determine the flight past points of the beginning of reading, then it is sufficient to simply be limited by systematic control of the path in terms of distance and direction.

In the case when the axis X is the mean orthodromic direction of the route, and the grivation is the initial azimuth of this direction, on the flight map it is necessary to plot this mean orthodromic direction and to mark the position of the aircraft relative to it with the aid of a scaled rule.

The wind velocity and direction with the aid of the NI-50 are determined in the following manner:

1) during flight past a reference point on the route the pointers "S" and "V" are placed on zero, we set the grivation, and on the wind controller - the indices of the wind velocity and direction also to zero:

2) every 15-20 min of flight by any of the available methods we determine the aircraft position  $MS_1$  and simultaneously

MS<sub>2</sub> ("no-wind position") according to the position and homing indicator. Both points are plotted on the flight map;

3) points MS<sub>1</sub> and MS<sub>2</sub> are connected by a straight segment, which will be the wind vector for the time counted from the moment of setting of the pointers of the indicator to zero. By division of the length of the segment in kilometers by the time in hours we determine the wind velocity in kilometers per hour. The wind direction will be the direction of the vector from MS<sub>2</sub> to MS<sub>1</sub>.

Flight past a reference landmark, the visual or electronic identification of which is impossible, is determined in the following manner:

1) by any available means we precisely determine the moment of flight past some reference point, the distance from which to the KO of interest to us is known;

2) during flight past the first reference point we move pointer "S" to the left of zero to a distance equal to the distance between reference points, in this case the wind parameters on the controller should be established;

3) the moment of passage of the zero position by pointer "S" will correspond to flight past the reference point of interest to us.

During flights over a limited area under conditions of frequently changing aircraft course, when control of the path is difficult, it is advantageous to use the NI-50 in the following manner:

1) we select a well identified reference landmark in the flying area;

2) on the flight map we place a grid of rectangular coordinates, arranged depending on the position of the reference landmark so that one of their axes would coincide with the true meridian of the reference point, i.e., the grivation is taken equal to zero;

3) during approach to the reference landmark the pointers "S" and "V" are set on zero, wind data at the flight altitude are introduced by the controller, and the grivation is taken equal to  $360^\circ - \Delta_m$ , if the automatic device operates from the GPK. In this case pointer "S" will indicate the MS along axis  $ox$ , and pointer "V" - along axis  $oz$ ;

4) in flight we monitor the path, routinely writing the MS on the map according to the readings of pointers "S" and "V" and using the grid applied on the maps for this.

#### AIRCRAFT DOPPLER RADAR SYSTEM

The aircraft Doppler system is a self-contained radar system of air navigation. The Doppler system to a considerable degree is free from such deficiencies in panoramic radar sets as their low efficiency in flight over uniform terrain, large expenditure of time for determining navigational elements (ground speed and drift angle) and the low accuracy of these measurements.

The aircraft Doppler system completely solves the problems of determining the navigational elements and dead reckoning.

The Doppler systems of air navigation, used in civil aviation of various countries, measure the ground speeds from 130 to 1800 km/h, and drift angles - from 0 to  $45^\circ$  at altitudes up to 15,000 m and higher. In this case errors on ground speed lie within limits from 0.2 to 0.9% and on drift angle within limits from 0.2 to 0.6, and the accuracy of dead reckoning with respect to

distance and lateral deviation with accuracy of compass course  $\pm 0.5^\circ$  is 1% of the distance.

**The operating principle.** If from the moving aircraft with the aid of a radio transmitter we emit electromagnetic oscillations at angle  $\theta$  to the earth's surface, then between the frequency of these oscillations and the frequency of oscillations, there will be detected drift reflected from the earth's surface, received by the aircraft radio receiver. The phenomenon of such an oscillation frequency drift is called the **Doppler effect**, and the difference of frequencies of radiated and received oscillations is called **Doppler frequency**. This frequency, as applied to the moving aircraft, is determined thus:

$$f_{\text{Dop}} = \frac{2W}{\lambda} \cos \theta,$$

where  $W$  - relative aircraft speed;  $\lambda$  - wave length;  $\theta$  - angle between the direction of aircraft motion and the direction of radiation.

The ground speed in the Doppler system is schematically determined in the following manner:

the aircraft radio transmitter through the antenna, in the direction coinciding with the longitudinal axis of the aircraft, emits radio waves with constant frequency of oscillation to the surface of the ground at a certain angle;

the radio waves, which fall to the earth, change their frequency in proportion to the ground speed of the aircraft and, being reflected, partially return to the aircraft, again changing their frequency; in this way, radio waves return to the aircraft with frequency changed twice in proportion to the longitudinal component of the ground speed;

the difference of transmitted and received radio wave frequencies is automatically measured with the aid of a special device, sending this value to a digital instrument.

The determining of the drift angle occurs according to a similar principle, but there is used an antenna directed perpendicular to the longitudinal axis of the aircraft.

Doppler systems can have single-beam, double-beam, three-beam and four-beam antennas. However, not the most widely applied are four-beam antennas (Fig. 54), since they eliminate a number of errors and increase the accuracy of measurement of the ground speed and drift angle.

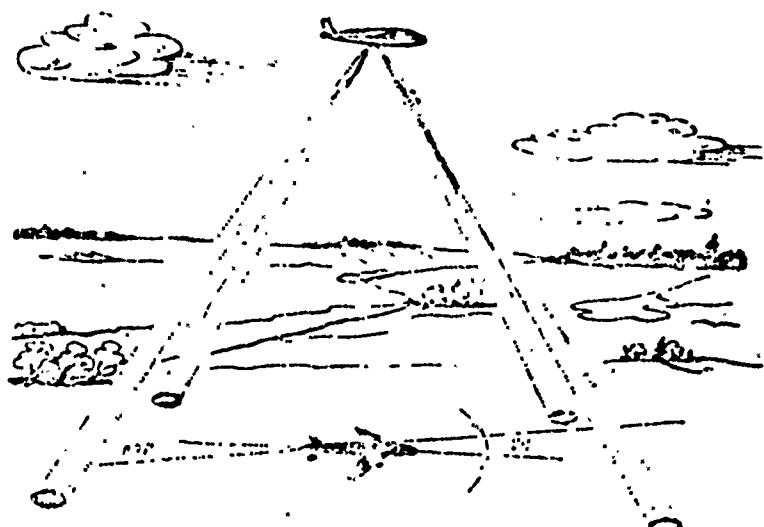


Fig. 54. The radiation of four-beam antenna.

Usually the Doppler systems (Fig. 55) include three basic devices, placed on the aircraft:

- 1) Doppler speed and drift meter (DISS), continuously determining the current values of  $W$  and  $US$  and sending them to the indicator (Fig. 56), and also to the navigation computer;

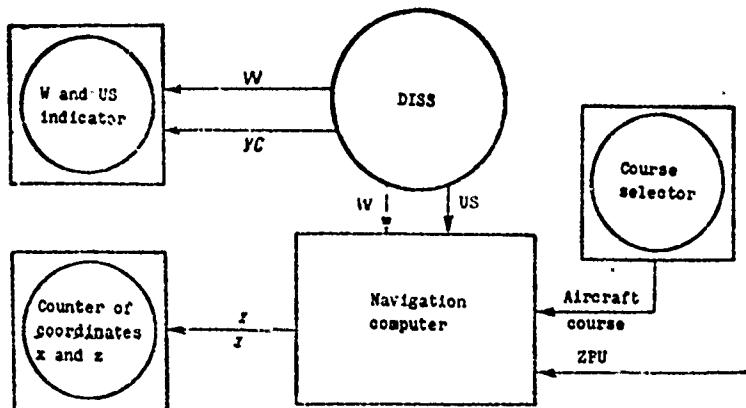


Fig. 55. Schematic diagram of the Doppler system.

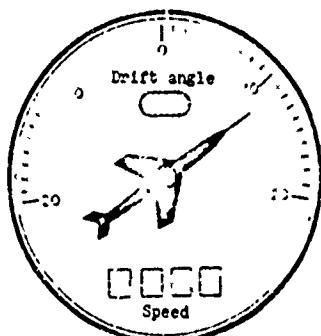


Fig. 56. Drift angle and ground speed indicator.

2) course selector;

3) the navigation computer (NV), receiving the current value of W and US from the DISS, and the aircraft course - from the course system, integrating these data and guiding dead reckoning in the great circle rectangular coordinate system. The NV gives the current position of the aircraft to the crew.

Coordinates x (path, passed by the aircraft along the assigned great circle) and z (linear lateral deviation from the great circle) are fed to a pointer-type instrument and digit counter.

The NV solves the equation which connects through elements of aircraft motion (ZPU, OK, W, US) and time the initial coordinates with the current coordinates of MS, whereupon the ZPU is introduced into the computer manually, OK - from the course system and US - from the DISS.

The basis for calculation is the determining of the difference between the actual and assigned OPU, i.e., lateral deviation

BU OK : (± US) - ZPU.

The distance, passed along great circle x, and the linear lateral deviation are obtained by integration of components  $W_x$  and  $W_z$  with respect to time:

$$x = \int_0^t W \cos BU(t) dt;$$
$$z = \int_0^t W \sin BU(t) dt.$$

since

$$W_x = W \cos BU; \quad W_z = W \sin BU.$$

The greatest error, which determines the accuracy of NV, is the error of the course selectors - course systems. Errors of the measurement and setting of the OK, and also the errors of determining W and US of the DISS have smaller value.

Navigation computers of type NI-50 accomplish dead reckoning according to the W and US being issued by DISS, but can also be used with manual introduction of the speed and wind direction. These computers similar to the NI-50 have a two-pointer x and z coordinate counter (pointers "S" and "V"), gravitation reference input element and the wind controller. The navigation computers, entering the Doppler systems, ensure the operation of the system in the "Memory" mode (the storage of parameters of aircraft motion in cases of flight over calm water spaces or at large banks), when entry into the system of Doppler frequencies is not observed. In this case while maintaining the airspeed and heading the dead reckoning will be carried out with permissible errors for 15-20 min.

Upon transition to the "Memory" system operating mode it

is advisable to place the "DISS - ANU" switch in the "ANU" position and with change in the airspeed or heading on the wind controller manually set the wind parameters and the grivation, since in this case the flight made was disturbed (W and US were changed with respect to those which the navigation computer "remembered"). In this case the values of the airspeed components along the axes of coordinates are added to the values of wind components along the same axes. Now with change of ZPU and setting of the new grivation the wind component is automatically redistributed.

The navigator's preflight action with the use of the Doppler system is performed in accordance with the requirements of the manual for the navigation service with respect to flight with great circle track angles. It is necessary to remember that the accuracy of air navigation depends upon the accuracy of calculation of the assigned great circle track angles and distances. Consequently, during preflight it is best to compute these data analytically, without resorting to measurements on the map. Formulas for the calculation of great circle track angle and great circle distance are given in the section "Aviation cartography".

Besides the precomputations of OPU and  $S_{opt}$ , during preparation of the flight map it is necessary to:

mark along the route the radar reference landmarks every 150-200 km depending on the extent of the route and the aircraft speed, calculate analytically or measure the rectangular coordinates x and z of these reference points, write them with the map and connect the reference point with the LZP by a straight line, perpendicular to the LZP (or to its continuation);

do the same for the points of installation of ground beacons of the azimuth and range system;

for each PPM write the value of the angle of turn (UR) for approach to the LZP of the following leg.

These additional operations are necessary for:

- a) ensuring precise flight over the IPM or fine adjustment on the counter of initial coordinates relative to the LZP laid on the map;
- b) correction of MS without measurements on the map with the aid of the panoramic radar or azimuth and range system;
- c) the precise determination of flight past the points necessary to us (KO, PPM, KPM) without measurements on the map.

The complete set of controls and the indicator of the Doppler system includes:

- 1) the drift angle and ground speed indicator (see Fig. 56);
- 2) the gravitation setting mechanism (assigned OPU);
- 3) the wind setting mechanism (for establishing the wind velocity and direction, when the DISS is not operating);
- 4) the counter of coordinates x (pointer "S") and z (pointer "V");
- 5) the control panel of the system in flight (Fig. 57), which has two signal lamps and two switches.

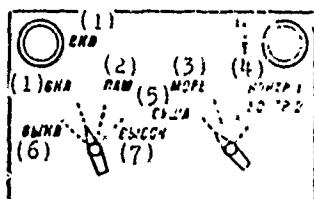


Fig. 57. Control panel.  
KEY: (1) On; (2) Mem.; (3) Sea;  
(4) Ck. 1, CK. 2; (5) Dry land;  
(6) Off; (7) High.

The first switch has four positions:

"Off" - the power supply of low voltage is turned off;

"On" - power supply of low voltage is turned on and the green (left) signal lamp with the label "On" lights up;

"Mem" - transfer of the system to the "memory" operating mode.

"High" - the power supply of high voltage is turned on and the red (right) signal lamp lights up.

The second switch also has four positions:

"Dry land" - position during flight over dry land;

"Sea" - position during flight over the sea;

"Ck. 1" and "Ck. 2" - position when checking the calibration of the system;

b) switch "DISS - ANU", making it possible to use the navigation computer (ANU, NI-50) in the case of failure of the DISS. In this case it is switched from the "DISS" position to the "ANU" position and the ANU conducts dead reckoning as the NI-50;

7) the "Counter" switch, designed for turning the coordinate counter on and off. At the moment of its transfer to the "On" position the navigation computer of the ANU performs calculation and feeds coordinates x and z to the counter. With setting of the switch in the "Off" position the pointers "S" and "V" do not move.

If it is proposed to use the Doppler system in flight, then before takeoff the navigator must:

- 1) on the control panel set the left switch in the "Off" position, and the right - in the "Dry land" position;
- 2) place toggle switch "DISS - ANU" in the "DISS" position;
- 3) check that the "Counter" switch stands in the "Off" position and the pointers of the dead reckoner are in the zero position;
- 4) on the grivation setting mechanism establish the assigned great circle track angle of the first leg, after which on the control panel transfer the left switch to the "On" position (the green signal lamp with the label "U." should light up);
- 5) in the air (not earlier than 2 min after turning on) set the left switch on the control panel in the "High" position (the red signal lamp should light up).

In 3 min it is possible to use the Doppler system, taking into account that the pointers of the dead reckoner will be in the zero position until the "Counter" switch stands on "Off", whereas the ground speed and drift angle indicator is in the operating position.

Despite the fact that the Doppler system in essence ensures the complete monitoring of the path, in view of the errors inherent in it basically because of the poor accuracy of determining the course, it is necessary for the crew in flight as precise as possible to exhibit the initial coordinates of MS, at the proper time by the navigational flight plan to correct the readings of the system with the aid of other electronic means and to operationally accomplish the transfer to the new leg.

Initial coordinates of MS can be considered either the coordinates of the place of departure, if after takeoff a circle is performed over the airfield, or the coordinates of the IPM - any point at some distance from the airfield, the precise flight past which is easy to "fix" with the aid of airborne radar, homing stations or azimuth and range system. In all cases it is desirable with the greatest possible accuracy at the moment of flight past the planned point to turn on the coordinate counter; if this for some reason is impossible, then visually or with the aid of electronic means determine the MS in rectangular orthodromic coordinates  $x$  and  $z$ , set them on the counter and turn it on, having established at the same time on the gravitation setting mechanism the value of OPU and having corrected the KS from the reference meridian. From the IPM to the first correction point accomplish flight with  $OK = ZPU - US$ , striving to hold the pointer of counter "V" (coordinates  $z$ ) in the zero position.

Active correction of the readings of the navigation computer in flight is accomplished with the aid of the aircraft panoramic radar or the azimuth and range system. For correction it is necessary to determine the actual position of the aircraft in orthodromic rectangular coordinates.

The formulas for determining the actual MS with the aid of radar and the azimuth and range system in essence are identical.

When using the locating sight:

$$x_{M,c} = x_{p,0} - D \cos PP;$$

$$z_{M,c} = z_{p,0} - D \sin PP,$$

when using the "Svod" system:

$$z_{M,c} = z_{p,0} + D \cos PP;$$

$$x_{M,c} = x_{p,0} - D \sin PP,$$

where PP - track bearing; D - the distance of the radar reference point or ground-based radio beacon of "Svod", and the difference

in signs is the consequence of the fact that in the first case there is taken the direction from the aircraft to the reference point, and in the second - from the beacon to the aircraft.

Activation and preparation of the system for operation. On the aircraft the Doppler equipment is turned on by the navigator. For turning on the equipment it is necessary:

1) on the control panel of the system to place the left switch in the "Off" position, and the right switch in the "Dry land" position;

2) to place the switch on the navigator's control panel with the label "DISS-ANU" in the "DISS" position;

3, to place the switch with the label "Counter", located near the dead reckoner, in the "Off" position;

4) to check that the pointer itself of the dead reckoner is in the zero position.

Having checked that all toggle switches and switches are in the indicated position ... the gravitation setting mechanism establish the assig. i great circle track angle of the first leg and transfer the left switch on the control panel to the "On" position: (on the control panel the green signal lamp with the label "On" should light up).

In 1-2 min. after turning on the system (after takeoff) the left switch on the control panel should be transferred to the "High" position, with this the red signal lamp with the sign  will light up.

After turning on the high voltage not earlier than in 3 min the system will be in working order and can be used for air navigation.

Since the "Counter" toggle switch is in the "Off" position, the dead reckoner does not operate and its pointers before turning on will stand on zero. The drift angle and ground speed indicators are in working order and issue the value of US and W.

Note: 1. When testing engines on the ground and in flight at altitude up to 200 m the "Route" equipment operates unstably.

2. Do not turn on high voltage on the ground in the "Dry land - Sea" mode.

#### AZIMUTH AND RANGE SYSTEM

The azimuth and range short-range navigation system continuously sends the current polar coordinates of the aircraft relative to the ground beacon of the system to indicator instruments.

The polar coordinates of the aircraft:

Azimuth, or true bearing of the aircraft (IPS) - angle between the northern direction of the true meridian, passing through the point of installation of the ground radio beacon, and the direction of the aircraft; the azimuth is projected to within  $0.25^\circ$ ;

range, or the distance from the beacon to the aircraft; measurement accuracy of range  $\pm 200$  m.

The system solves the following problems with high accuracy:

- a) continuous reading of the value of the azimuth to the aircraft and the range;
- b) air navigation along the assigned route;

- c) determination of navigational elements in flight;
- d) guiding the aircraft to any assigned point and the signaling of its flight past;
- e) ground observation, identification, determination of coordinates of the aircraft and control of its movement.

The operating principle. The azimuth is assigned by the time interval between the initial time of reading, identical for all aircraft located in the zone of coverage of the beacon and equipped with the corresponding equipment, and the moment of reception of the azimuth signal by each of these aircraft. The ground beacon of the system includes a transmitting azimuth antenna with narrow-beam radiation pattern (in horizontal plant), rotating at a speed of 100 rpm, and antenna of reference signals with omnidirectional radiation pattern. The northern reference signal is transmitted by this antenna at the moment of passage of zero azimuth by the azimuth antenna (northern direction of true meridian).

Thus the azimuth on the aircraft is determined by the time interval between the receivings of the northern reference signal of the omnidirectional antenna and the signal from the rotating azimuth antenna by the aircraft at the moment when it has been directed to the aircraft.

The ranging is accomplished according to the "interrogation - response" principle by means of measurement of the total propagation time of the interrogation signal from the aircraft to the ground and the response signal from the ground to the aircraft. This time is converted into the measured distance with sufficient accuracy, since the propagation velocity of electromagnetic energy is constant.

The ground beacon of the system has a plan-position indicator (IKO) to obtain on the cathode-ray tube face the marks of the aircraft, which perform flight in the zone of coverage of the beacon and are equipped with the equipment system. The IKO together with the command radio station added to it can be remote and be installed at the control tower.

The operating region of the system. The system operates in the UHF range and therefore its operating region is determined by the flight altitude and by the nonoperating funnel with radius equal to the flight altitude, located directly over the ground station.

The range of action of the stations, located on flat and slightly-broken terrain at the angles of coverage 0.5-1°, is calculated by formulas:

$$\rho_{\max} = 33.7(\sqrt{H_{\text{OM}}} + \sqrt{h_{\text{OTH}}});$$
$$H_{\text{OM}} = H_{\text{aOC}} - h_p; h_{\text{OTH}} = h_{\text{aOC}} - h_p,$$

where  $H_{\text{OTH}}$  - the flight altitude relative to the average height above the terrain ( $h_p$ );  $h_{\text{OTH}}$  - the altitude of the antenna of the beacon relative to the average height above the terrain ( $h_p$ );  $H_{\text{aOC}}$  and  $h_{\text{aOC}}$  - the flight altitude and beacon antenna height relative to sea level.

The controls of the system on the aircraft consists of three control panels:

main control panel (ShchU);

pilot's panel (ShchP);

control unit of computer device (EU SRP).

Furthermore, there is a switch for transfer from the navigation mode to the landing mode. It has three positions, one of which corresponds to operation of the null instrument in flight along the route, and two others - during landing approaches using SP-50 and "Svod" systems.

The main control panel of the system (ShchU) is usually placed in the navigator's compartment. On it are arranged (Fig. 58):

two handles (switches) 1 for setting the channel of the ground beacon, in the working zone of which at a given time the aircraft is located;

the function selector 3, which has seven positions: "Off KPP", "Azimuth to", "Azimuth from", "Orbit right", "Orbit left", "SRP" and "Landing". During the landing approach, besides setting the function selector to the "Landing" position, the special switch, which has three positions, is placed in the position "SP-50" either "Course-M" depending on how approach is performed using the system "SP-50" or "Svod";

handle 8 and scale 4 with the label "Azimuth" for setting the assigned value of azimuth (true bearing);

handle 7 and digital drum indicator with the label "Orbit" setting the assigned range 6 (to PPM, KPM or any reference point on the LZP);

two buttons 5 with the label "monitor", "Azimuth", "range" and "duration of strobe" for checking the operation of the system on the channels of azimuth, range and control of the strobe duration.

Pilot's panel (ShchP) is used when the appropriate beacons are installed at airfields.

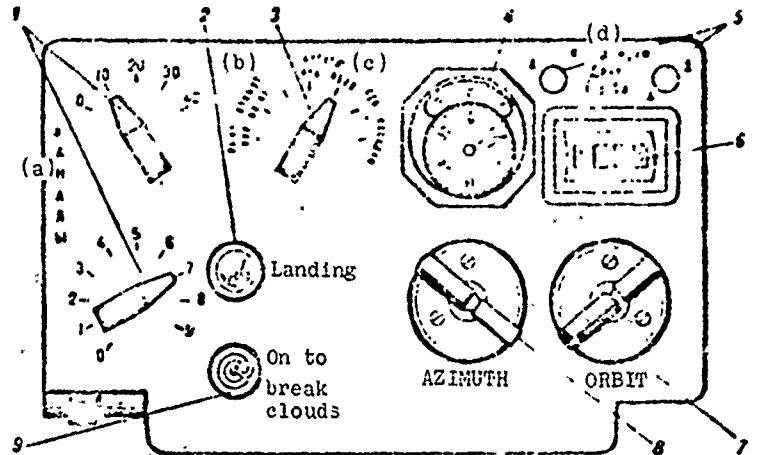


Fig. 58. The main control panel (ShchU): 1 - ground beacon channel setting switch; 2 - "Landing" lamp; 3 - selector switch of the kind of operations; 4 - scale of the azimuth setting mechanism (true bearing); 5 - buttons for checking the azimuth, range and duration of strobe; 6 - scale of the range setting mechanism (orbit); 7 - handle of the range setting mechanism (orbit); 8 - handle of the azimuth setting mechanism (true bearing); 9 - toggle switch "On to break clouds."

KEY: (a) Channels; (b) Off Azimuth; (c) Orbit, Left, Right, SRP, Landing; (d) Zero check for strobe.

The control unit of the computer is also placed in the navigator's compartment. On it are located (Fig. 59):

handle 1 and a scale with label "ZPU" for setting the value of the given true course angle relative to the reference meridian, passing through the point of installation of the ground beacon of the system (OPU);

handle 6 and a scale with label "Target angle" for setting the value of the true bearing (azimuth) of the terminal point of a given section of the route from the ground beacon;

handle 5 and digital drum indicator 4 with label "Distance to target" for setting the distance from the ground beacon to the terminal point of the given section of the route.

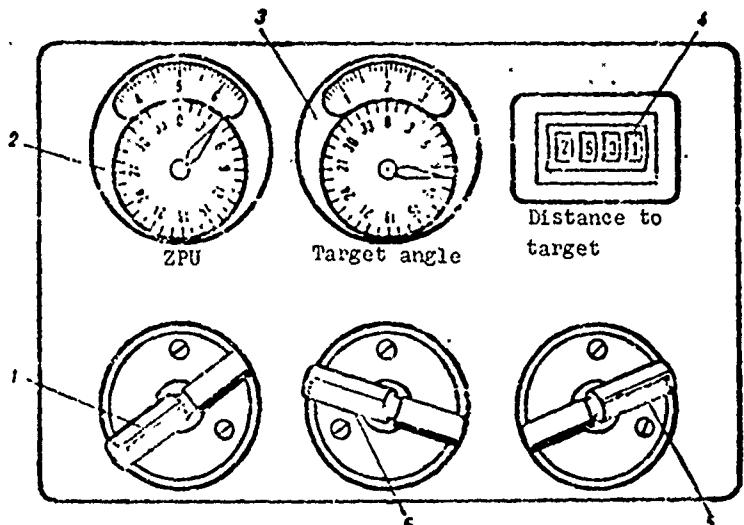


Fig. 59. Control unit of computer device (BU SRP): 1 - Handle of the ZPU setting mechanism; 2 - scale of the ZPU setting mechanism, read from the reference meridian; 3 - scale of the setting mechanism of the true bearing (azimuth) of the target (PPM, KPM, KO, etc.); 4 - scale of the range from the beacon to the target (PPM, KPM, KO, etc.); 5 - handle of the setting mechanism of the range to the target; 6 - handle of the setting mechanism of the true bearing (azimuth) to the target.

Indicators. On heavy transport planes the following instruments are installed:

1) the navigator's direct-reading range and azimuth instrument (PPDA-Sh) is located on the navigator's control panel (Fig. 60). The outside scale, along which the contour pointer moves, is enumerated every  $30^\circ$  with scale value  $10^\circ$  for the coarse reading of azimuth, and the inside scale with small pointer - every  $1^\circ$  with scale value  $0.1^\circ$ .

The digital drum indicator of the current range has four windows and gives reading to within 0.1 km;

2) the pilot's direct-reading range and azimuth (PPDA-P) is installed on the pilot's control panel (see Fig. 60a) and has only an outer scale and a large pointer for coarse reading of the azimuth;

3) the combined flight instrument (KPP) combines the course scale with the pointer of repeater of USh or GPK-52 and the null instrument, similar to instrument PSP-48, with the only difference that the vertical and horizontal pointers during all movements always retain mutual perpendicularity (Fig. 61). The course scale rotates with the aid of rack and pinion in the lower right corner of the instrument.

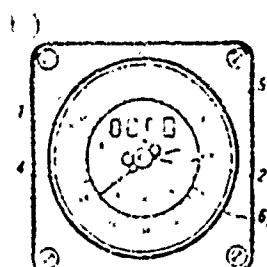
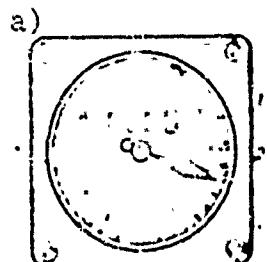


FIG. 60. Direct-reading azimuth and range instruments: a) pilot's (PPDA-P); b) navigator's (PPDA-W); 1 - digital drum current range indicator (accuracy of reading 0.1 km); 2 - azimuth coarse reading pointer; 3 - azimuth reading scale (accuracy of reading  $2^\circ$ ); 4 - azimuth fine reading pointer; 5 - outer scale of coarse reading of the azimuth (accuracy of reading  $10^\circ$ ); 6 - inner scale of fine reading of the azimuth (accuracy of reading  $0.1^\circ$ ).

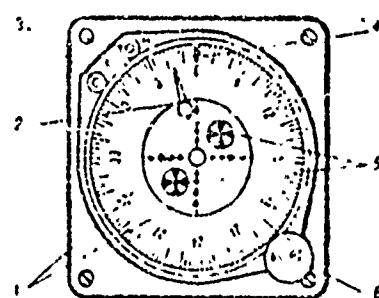


Fig. 61. Combined flight instrument (KPP): 1 - vertical and horizontal pointer of null indicator; 2 - movable scale and pointer of the course; 3 - setting screws of mechanical zero; 4 - fixed index; 5 - blinkers of course and glide path; 6 - rack and pinion of the course scale.

At the top of the scale there is a fixed orange triangular index. In the upper left corner of the instrument are two screws, designated by the letters of "G" and "K". Always before turning on the equipment with these screws one should set the horizontal

and vertical pointers on the center of the instrument (mechanical zero).

**Switch on, adjustment and testing of the airborne equipment:**

1. In 5-6 min before the beginning of operation switch on the aircraft equipment under voltage. Place the switch, which has three positions ("Svod", "SP-50" and "Course-M"), in the "Svod" position.
2. On the control panel (ShchU) set the channel of the appropriate ground beacon of the system and check the correctness of its setting. The construction of beacons provides for the issue of call signs, but at present these signals are not issued.
3. Set the selected kind of operation on the ShchU ("Azimuth", "Orbit" or "SRP"), whereupon by the handles of setting mechanisms on the appropriate scales set the initial data of the first leg. If flight will be performed in the "SRP" mode, then on the BU SRP the initial data are also exhibited.
4. Set the value of the given true course angle (ZIPU-OPU) with the aid of the rack and pinion opposite the fixed orange index of KPP instrument.
5. By the blinker of the vertical pointer of the KPP and by the signal lamps of the azimuth and range channels check the efficiency of the equipment, taking into account that the "search" mode lasts up to 5 min and only after "capture" of the signals of the beacon will the blinker be covered, and the signal lamps will go out.
6. By the check knobs on the ShU ("Azimuth", "Range" and "Duration of strobe") check the calibration of the range and azimuth scales, for which:

by pressing the check knob of the azimuth rotate the pointer of the precision dial of the PPDA-Sh. It should stop on the orange check digit "1°";

by pressing the check knob of the range rotate the two right drums of the counter, whereupon they should stop in the position "2.0". If this does not occur, then by the turning the pressed knob set the orange check figure "0" in the extreme (right) window of the counter.

7. By the left knob, utilized for calibration of the azimuth, adjust the strobe duration, for which pull out the knob, rotate the azimuth pointers of the PPDA-Sh. If the pointers do not stop on the value larger than  $4^{\circ}$  and less than  $5^{\circ}$ , then by turning the pulled-out knob bring the pointers to this value.

Note. Checking the calibration of the azimuth and strobe duration is accomplished only with the beacon operating.

#### Air Navigation with the aid of azimuth and range system

Flight in the "Azimuth" mode can be performed if the LZP, or its continuation, passes through the point of installation of the ground beacon of the system (Fig. 62). In this mode flight can be performed in two versions: "from the beacon" and "to the beacon." In the first case the IPS (azimuth) should always be kept equal to the ZPU, in the second - ZPU  $\pm 180^{\circ}$ . In both cases the value of the ZPU with the aid of turning of the course scale of the instrument of KPP is exhibited under the fixed orange index.

In all cases of flight the deflection of the vertical pointer of the null indicator to the left of the center of the scale attests to drift of the aircraft to the right of the LZP, and

deflection of the pointer of the null indicator to the right signals the left deviation of the aircraft from the LZP. Thus, the center of the dial face represents the aircraft, and the vertical pointer - the specified track.

For flight in the "Azimuth to" or "Azimuth from" mode on the ShchU the selector knob of the kind the operation is placed in the appropriate position, with the "Azimuth" handle on the scale we assign the value of A-ZIPU (or ZIFPU  $\pm 180^\circ$ ), and by the "orbit" handle on the setting mechanism we set the distance from the beacon to the first PPM, or to any point on the LZP necessary to us. During flight past this point the signaling should operate: 1-1.5 min before flight over on the pilot's panel a green warning lamp blinks, at the moment of flight over a red signal lamp flashes.

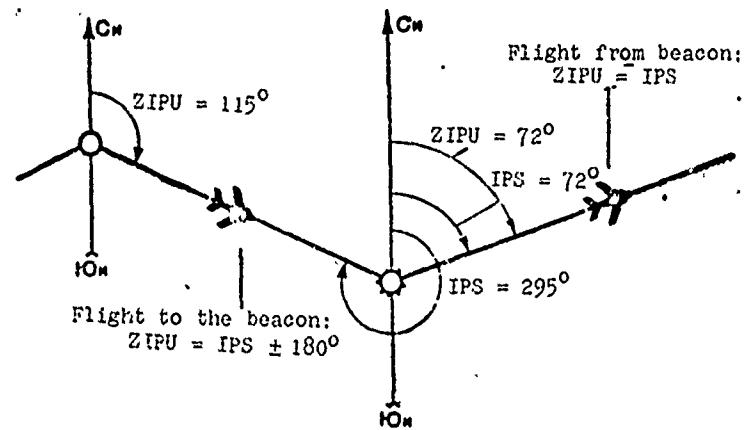


Fig. 62. Azimuth flight.  
Designations: C<sub>W</sub> = S<sub>i</sub> = true north; I<sub>W</sub> = Yui = true south.

The path with respect to range is checked by observation of the current range, its comparison with the range of reference points and by the ignition of signal lamps.

The drift angle during flight in the "Azimuth" mode will be equal to the angle between the course pointer of the repeater of USh (or GPK) of the KPP instrument and the fixed orange index

under the condition of keeping the vertical pointer of the null indicator strictly in the center of the scale.

The ground speed in this mode is determined in the following manner:

during flight from the beacon

$$w = \frac{D_2 - D_1}{t};$$

during flight to the beacon

$$w = \frac{D_1 - D_2}{t}.$$

Flight in the "Orbit" mode can be performed when the LZP coincides with the circumference, the center of which is the point of installation of the ground beacon (Fig. 63). During flight by the right orbit the beacon is always located to the right (right bank), during flight by left orbit - on the left (left bank).

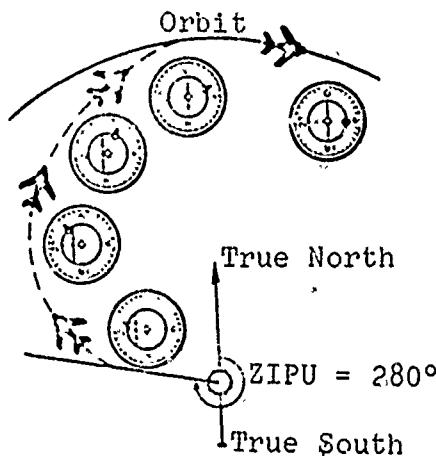


Fig. 63. Orbital flight.

For flight in this mode on the ShchU the operating mode selector is placed in the "Orbit right" or "Orbit left" position, the "Orbit" handle on the drum counter of the setting mechanism radius of the orbit is exhibited, which remains constant for the extent of the flight in this mode, and by the "Azimuth"

handle on the scale we set the IPS in the first PPM or at any point on the assigned orbit of interest to us. During the approach to this point light signaling is activated.

Checking of the path with respect to range is accomplished by comparison of the current IPS with the true bearings of reference points and with the aid of light signaling of approach and flight past.

During flight along an orbit one should also use a null indicator, however drift here will be the same as the IPU, constantly changed. The ground speed also is continuously changed, but for the section of the path being passed it can be determined by formula

$$W = R \frac{\Delta \text{IPS}}{57.3t},$$

where R - radius of orbit, km;  $\Delta \text{IPS}$  - change of IPS during the time of measurement, degrees; t - time of measurement, h.

Flight using a computer (SRP) is performed when the L2P coincides neither with the true bearing line, nor with the orbit. This - flight along any straight line within the limits of action of the ground beacon of the system (Fig. 64).

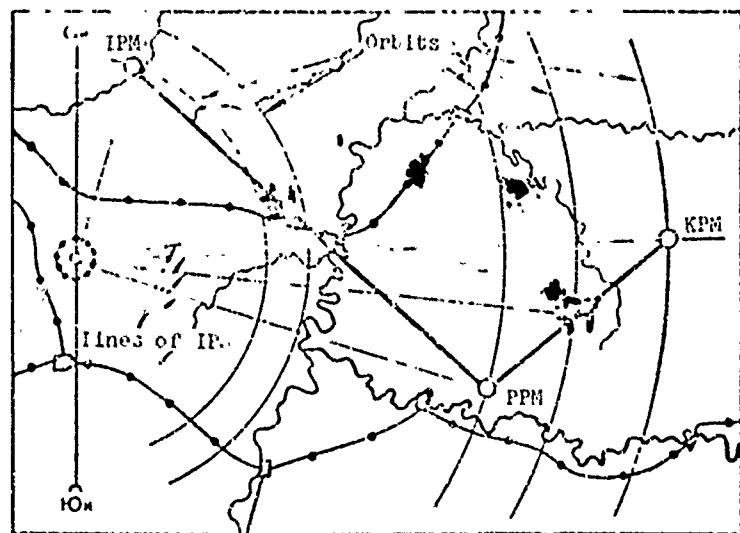


Fig. 64. Flight with the aid of SRP.

In this case on the main control panel (ShchU) the operating mode selector knob is placed in the "SRP" position, and for piloting according to the null indicator all the data are already set on the control unit of the SRP (BU SRP).

On the BU SRP we set the following data:

by the handle "ZPU" on the appropriate scale we set the given true course angle (ZIPU), read from the true (reference) meridian, passing through the point of installation of the ground beacon of the system;

by the "Target angle" handle on the appropriate scale we assign the true bearing (azimuth) of the terminal point of the given section of route;

by the "Distance to target" handle we assign the range of the terminal point of the given section of the route from the ground beacon.

Under the fixed orange index of the KPP instrument by the rack and pinion we supply the value of ZIPU and with retention of the vertical pointer of the instrument in the center of the scale the aircraft follows the LZP. The behavior of the pointer with deviation of the aircraft to the right and to the left of the LZP will be the same as during flight along azimuth or orbit.

The drift angle is determined by the same method as during flight along an azimuth.

For checking the path with respect to the range and for determining the ground speed the entire route is broken down into check sections. Around the marks are recorded their polar coordinates (azimuth and range) and, by accurately timing the flight past the selected base, we determine  $W$  by formula

$$W = \frac{S}{t},$$

where  $t = t_2 - t_1$ .

For the activation of signaling during flight by SRP on the main control panel (ShchU) one should also set: by the "Azimuth" handle - the true bearing of the terminal point of the given section of route (or any other KO on the LZP), and by the "Orbit" handle - the distance from the beacon to this point. Since flight using the SRP is accomplished with somewhat lower accuracy than flight in the "Azimuth" or "Orbit" mode, only the signal of approach to the "target" can operate, the flash of the red signal lamp may not follow. In this case it is necessary to determine the magnitude of BU with the aid of PPDA and introduce the appropriate correction to the flight course.

If as the "target" we take the reference point (the traverse point of the beacon being flown over), flight is accomplished in the following manner:

1. On the main control panel (ShchU), besides the channel of the ground beacon and the operating mode (SRP), there is installed the "Orbit" and "Azimuth" of the final or turning point of the route (or any reference point on the route, the flight past which is desirable to determine).

2. On the BU SRP on the selector "Target angle" there is exhibited the true bearing of the reference point (the target angle is equal to ZPU  $\pm 90^\circ$ ), on the selector "Distance to target" - the distance from the ground beacon to the reference point and on the selector "ZPU" - the given true course angle relative to the meridian, passing through the point of installation of the beacon.

3. On the KFP instrument with the aid of rack and pinion opposite the triangular index we set the value of the ZPU.

The approach to the specified track is performed identically, regardless of which point is taken as the target in the given flight.

1. In order to bring the small circle of the course pointer of the KPP instrument to the upper edge of the vertical lath of the instrument, it is necessary to turn the aircraft toward the LZP it is advantageous to bring the course pointer to the position perpendicular to the vertical lath of the instrument, for faster approach to the LZP.

2. Hold the upper end of the vertical lath of the instrument in the small circle of the course pointer until its coincidence with the triangular index.

3. On the arrival of the vertical lath to the center of the scale, while continuing flight, hold it in the center, without paying attention to the small circle of the course pointer. The position of the lath in the center of the scale indicates that the aircraft is located on the LZP, and deflection of the course pointer to the right or left shows the amount and sign of drift.

4. While continuing to hold the vertical lath in the center of the scale, mark the average flight course of the aircraft and with the aid of the rack and pinion bring it to the triangular index.

5. Fly the aircraft by the course pointer, observing the behavior of the vertical lath. If the vertical lath exceeds the small black circle, by turning the aircraft again bring it to the center of the scale and refine the earlier taken flight course.

6. Perform further flying by the course pointer with continuous monitoring of the path in terms of range and direction.

Since during flight in arbitrary direction the range and azimuth continuously change, for range and azimuth monitoring of the path it is convenient to have preplanned reference points, the ranges and azimuths in which are already measured. In this case depending on the convenience in each concrete case it is possible to use two methods:

1. With agreement of the current azimuth with check, compare the current range with the check.
2. With conformity of the current range to check read the current azimuth and compare it with calculated.

Flight by SRP with the method of setting the coordinates of the reference point, as the "target" coordinates, on the BU SRF has a number of advantages with random or intentional deviation from the LZP.

1. The linear lateral deviation is determined by rotating the known "Distance to target" until the vertical lath of the KPP arrives at the center of the scale. The difference of the read distance and the distance to the reference point, established earlier, will be the desired LBU. After determining the LBU for approach the necessary point on the BU SRF one should set the coordinates of this point and, by rotating the "ZPU" knob till the arrival of the vertical pointer of KPP at the center of the scale, from the "ZPU" selector compute the value of the true track angle for the further following of it to the selected point, while holding the lath on the scale zero.

2. If there is given the instruction to follow parallel to the LZP at a certain distance from it, it is sufficient to only increase or decrease by the assigned value the distance to the reference point exhibited on the setting mechanism of BU SRF and to continue flight in the usual order. This is especially

convenient for the purposes of lateral separation of aircraft following at one altitude.

3. If during tracking to the beacon (mode of operation "Azimuth to") there appeared the necessity or there was received the instruction to fly past the radio beacon at a prescribed distance from it (flight along rectangular route, etc.), on the BU SRP one should set the given true course angle, equal to the azimuth changed  $180^\circ$ , set on the ShchU during beacon tracking, on BU SRP - "Target angle", equal to exhibited ZPU  $\pm 90^\circ$ , on BU SRP - "Distance to target", equal to the prescribed distance from the beacon. On the ShchU move the operating mode selector handle from the "Azimuth to" position to the "SRP" position and further follow in the usual order, using the null indicator and coordinates of the point set on the ShchU selectors, the signal about flight past which is necessary for accomplishing the maneuver.

#### Preflight Action with the use of the Azimuth and Range System

The azimuth and range system should be used in flight in the set with the other autonomous and nonautonomous systems and means of air navigation. Therefore its use does not exclude the usual established order of the preflight action. If for flight along the planned route the crew does not have available the tables with prepared data (Table 23), in order to more fully use the possibilities being given by the use of the system, the following additional operation should be completed for it:

- a) through the points of installation of all the ground beacons planned for use draw the true (reference) meridians;
- b) in the zone of coverage of every beacon mark off the LZP in great circle track angles relative to the reference meridian of this zone;

Table 23. Moscow - Sochi flight route.

Section no.	Section of route	Beacon and operating mode	PPM (km) deg	PPM deg	Km (mi)
1	Stupino-Venev	Vnukovo SRP	167.5	154.5	152
2	Venev-Zadonsk	Vnukovo SRP	167	161.5	37
3	Venev-Zadonsk	Voronezh Azimuth to	-	349	75
3	Zadonsk-Voronezh	Voronezh Azimuth to	-	349	-
4	Zadonsk-Petrovskoye	Voronezh Azimuth from	-	90	-
3, 4	Zadonsk-Petrovskoye	Voronezh SRP	130	90	72
5	Petrovskoe-Krasnovka	Voronezh SRP	180.5	168	330

Note. For the convenience of use of tables for every section they include only the data being established on the appropriate setting mechanisms of the main ShU or BU SRP for flying by the null indicator of KPP-M. Therefore the coordinates of all the other points on the LZP, signals of flight past which are desirable to obtain, should be recorded on the back of the table.

In the table by the same number there are given the sections arranged simultaneously in the coverage zones of two or more beacons. If in such a section there arises doubt of the reliability of operation of the utilized beacon, it is possible to easily change to the operation with another. In the tables can also be a section which has two numbers (for example section 3, 4). This means that the given section is the rectifying one for sections 3 and 4.

c) around all reference landmarks, PPM, etc. write the values of the azimuth and range relative to the beacon, in zone of which the given section of the route will lie;

d) divide the LZP into 50- or 100-kilometer check sections with the plotting of their polar coordinates at the marks in order to always have the capability of selecting any base for determining the ground speed.

It is recommended to make these additional writings and notes on the map for the adjoining working zones of two ground beacons with India ink of various colors.

## FOREIGN ELECTRONIC SHORT-RANGE NAVIGATION SYSTEMS

### General Knowledge

As the basic means of short-range navigation in the ICAO organization there are accepted VOR, VOR/DME, VORTAC and TACAN systems. These systems operate in the VHF range and provide determination of the azimuth, range or both these magnitudes simultaneously for aircraft relative to a ground omnidirectional beacon.

Below are given the data of aircraft radio equipment, which ensures the reception of signals of the VOR omnidirectional beacon. Usually these radio receivers provide not only the reception of signals of the VOR beacon, but also the signals of the course beacon of the ILS landing system.

Recently on foreign aircraft the DME range finders are being replaced by the range-finding units of TACAN equipment, since the range-finding part of the TACAN system gives high accuracy as compared with the DME system. In such an assembly the system obtained the name VORTAC. Furthermore, the TACAN system gives high accuracy in azimuth in comparison with the VOR beacon, and also in the TACAN system there is provided a transmission line of data from the aircraft to the ground and back. This system is gradually replacing the VORTAC system.

### VOR<sup>1</sup> RADIO SYSTEM

The aircraft equipment VOR - ILS, SR-32 or SR-34/35 provides air navigation by VOR ground beacons and the execution of landing approach using the ILS system.

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<sup>1</sup>The chapter is written by V. A. Belyatskiy.

During operation in the "VOR" mode this equipment makes it possible to solve the following navigational problems:

determine the magnetic bearing of the ground VOR radio beacon<sup>1</sup>;

execute flight along the ZMP of the ground radio beacon;

determine the aircraft position according by the magnetic bearings of two VOR radio beacons;

determine the drift angle in flight.

The range of the VOR system (beacons with power 200 W) is within limits, km:

when  $H = 300$  m ..... 60-90

when  $H = 1500$  m ..... 130-170

when  $H = 6000$  m ..... 280-320

when  $H = 9000$  m ..... 330-370

Maximum range - during flights over flat terrain and sea. The accuracy of determining the bearings of VOR radio beacons with the aid of airborne equipment is characterized, as a rule, by error 2-3°. During flights in mountain regions the errors can reach 5-6°.

During operation in the ILS modes the airborne equipment makes it possible to execute the landing approach by signals of the course and glide-path radio beacons of the ILS system with the aid of a course and glide-path indicator.

The range of the ILS system on the course channel at flight

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<sup>1</sup>The magnetic bearing of the beacon is always read from the meridian of the place of installation of the beacon.

altitude  $H = 600$  m is not less than 45 km, on the glide path channel at  $H = 400$  m - not less than 18 km.

Equipment SR = 32 and SR = 34/35 operates at frequencies 108-117.9 MHz and has 100 channels, which are divided between the VOR and ILS systems in the following manner:

the odd frequencies in the range 108.1-111.9 MHz - for course beacons of the ILS system;

even frequencies in the range 108.0-112.0 MHz - for beacons of the VOR system;

all frequencies in the range 112.0-117.9 MHz - only for beacons of the VOR system.

At present the VOR beacon frequencies, as a rule, are established from frequency 112.0 MHz and higher. With setting of the frequency of the course beacon of the ILS system the airborne glide-path receiver of SR-32 and SR-34/35 equipment is simultaneously turned on.

Ground equipment of the VOR system - is a VHF - omnidirectional radio beacon.

There are two types of radio beacons:

1) VOR radio beacons with power 200 W (power input 7 kVA) to provide flights along airways;

2) radio beacons of reduced power - 50 W (power input 5 kVA), designed for installation at airports.

The omnidirectional VOR beacon emits a signal, which consists of carrier (in the range from 108 to 118 MHz) frequency,

modulated by two low-frequency signals (30 Hz). The phase difference of modulating frequencies, measured at any point of the operating zone of the radio beacon, is proportional to the aircraft azimuth relative to the given (reference) direction. Usually as reference direction we take the direction to north; along this direction both modulating frequencies are in phase.

During aircraft motion clockwise relative to the point of installation of the beacon the phase of one of the modulating frequencies changes, whereas the phase of another, which is reference, remains unchanged. This is attained by separate emission of carrier and side frequencies, whereupon the signals of side frequencies of the reference phase create a nondirectional pattern in horizontal plane, and the signals of side frequencies of variable phase in horizontal plane create a directed diagram in the figure-eight form.

All radio beacons of the VOR system operate automatically and are remote controlled.

At present VOR beacons with high-altitude markers are installed, which, because of signaling, transmitted aboard the aircraft, make it possible to more accurately determine the moment of flight over the beacon. In order to distinguish one radio beacon from another, each of them are given its own call signals, which are two or three letters of the Latin alphabet, transmitted by telegraphic code. The listening of these signals aboard the aircraft is conducted through the SPU.

The ground equipment of the ILS system consists of the course and glide-path radio beacons and three radio marker beacons: outer, middle and inner (at present the inner marker is not installed at all airports). In some airports for the formation of a maneuver during landing approach on the outer marker point or outside it (in the alignment of the axis of the course zone of the ILS system) a homing station is installed.

There are two versions of the placement of ground equipment:

- 1) radio-range beacon is arranged on the axis of the runway;
- 2) when the radio-range beacon is arranged to the left or right of the axis of the runway so that the axis of the course zone passes through the middle or inner marker point at 2-8° angle to the continuation of the runway axis. At any airport the outer marker point of the ILS system is installed at a distance of 7400 m, the middle marker point - 4000 m, and inner - 1050 m from the beginning of the runway.

The control units and indicating instruments of SR-32 equipment. For adjustment of the equipment and the taking of readings in flight the crew uses the following instruments:

control panel of SR-32 (Fig. 65);

Indicator-setting mechanism of the radio beacon bearing (SR-32) (Fig. 66);

two course and glide-path indicators (null indicators) (Fig. 67).

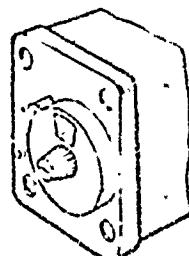


Fig. 65. The control panel of aircraft electronic equipment SR-32.

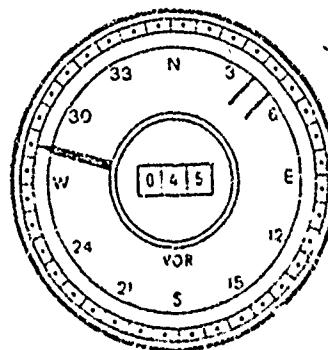


Fig. 66. The indicator-setting mechanism of the radio beacon bearing (SR-32).

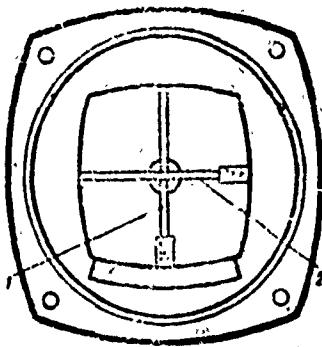


Fig. 67. Course and glide-path indicator (null indicator): 1 - course pointer; 2 - glide-path pointer.

Note. On some Tu-104 aircraft due to the operation of glide-path receivers SR-32 and GRP-2 from one antenna there has been provided an antenna relay switch with the label "SP-50 - ILS."

The control panel of SR-32 equipment and the bearing indicator-setting mechanism are located at the navigator's working position. The control panel has two handles for setting the value of VOR or ILS frequencies. When setting the appropriate frequency on the pilot's instrument panel one of the signal lamps with the designation "VOR" or "ILS" lights up. The course and glide-path indicators are located on the instrument panels of the aircraft commander and the right pilot. On some aircraft they ensure aircraft handling not only by the signals of VOR and ILS beacons, but also make it possible to land by the SP-50 system.

**The set of VOR - ILS, SR-34/35 airborne equipment.** The VOR - ILS, SR-34/35 airborne equipment installed at present has the following control units and indicators:

SR-34/35 control panel (Fig. 68);

azimuth selector (Fig. 69);

radiomagnetic indicator (Fig. 70);

two course and glide-path indicators (null indicators) (see Fig. 67).

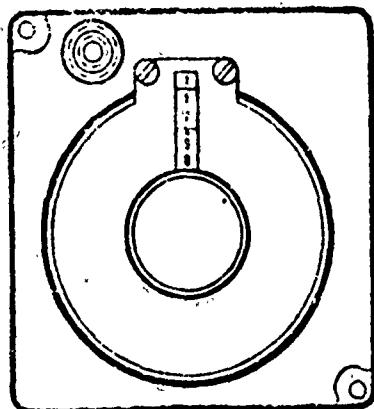


Fig. 68. Control panel of SR-34/35.

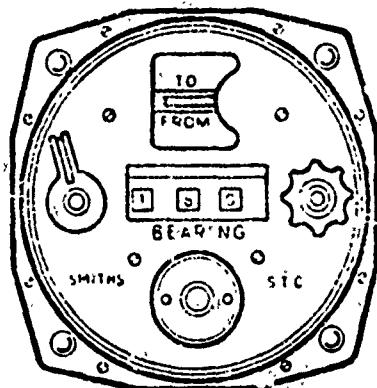


Fig. 69. Azimuth selector.

Control panel of VOR-ILS equipment, as in the SR-32 equipment has two handles for the setting the fixed "VOR" or "ILS" frequencies.

The azimuth selector instrument serves for setting reading the values of the given magnetic bearing of the beacon (or ZMPU), and the pointer "TO - FROM" indicates the position of the aircraft relative to the beacon:

position "TO" - flight to the VOR beacon;

position "FROM" - flight from the VOR beacon.

For flight along the specified track on the azimuth selector there is manually set the value of the ZMPU and if the vertical pointer of the course and glide-path indicator is held in the center, it is possible to consider that the aircraft is on the specified track. Flight past the beacon is noted by the pointer "TO-FROM". The readings of this pointer depend only upon the setting of the value of the ZMPU and the position of the aircraft relative to the beacon and do not depend upon the magnetic course of the aircraft. With switching of the value of the ZMPU the readings of the vertical pointer of the course and glide-path indicator are changed to the opposite.

Radiomagnetic indicator (RMI) indicates the values of MPR relative to the place of installation of the beacon (from 0 to 360°). Simultaneously on this instrument it is possible to read the magnetic course of the aircraft and the VOR radio beacon heading. The magnetic course of the aircraft is read on movable scale relative to a fixed index. This combined instrument is convenient for flying, since the pointer, indicating the MPR relative to the movable scale, simultaneously shows the radio beacon heading on the fixed scale (see Fig. 70). On the RMI are two combined pointers, which show the values of the MPR from two of VOR equipment on the aircraft.

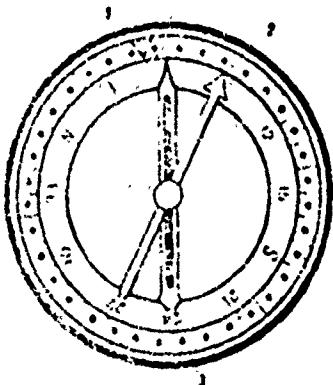


fig. 70. Radiomagnetic indicator (RMI): 1 - Magnetic course indicator; 2 - indicating pointer of the radio beacon heading and the magnetic bearing of the radio beacon; 3 - pointer, which indicates magnetic bearings and headings, working from the second set of SR-34/35 equipment.

When setting up the two sets of VOR-ILS, SR-34/35 airborne equipment there are installed two control panels, two azimuth selectors, two radiomagnetic indicators, two course and glide-path indicators (for the first and second pilot respectively).

#### The use of VOR-ILS Equipment in Flight

**Ground preparation.** For the use of VOR-ILS equipment in flight it is necessary to know the precise coordinates, frequencies and call signs of ground radio beacons, their location relative to the assigned track (individual sections of the route).

For making it easier to determine and plot bearings on the map we place the azimuth circles with center at the place of installation of the radio beacon with scale value  $5^\circ$ . The scale zero of these circles is matched with the northern direction of the magnetic meridian of the radio beacon. At the circle there should be labels (Fig. 71) with indication of the name of the point, place of location of the radio beacon, frequency of its operation and call sign (with letters of telegraphic code).

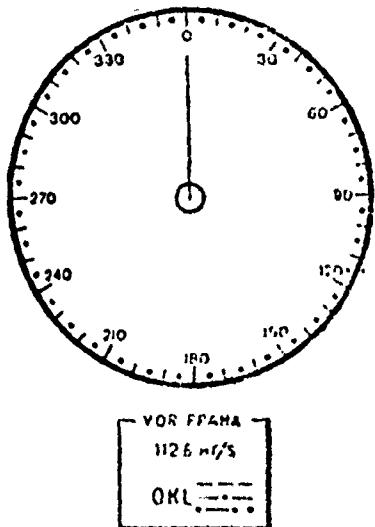


Fig. 71. Map symbol of VOR beacon (azimuth circle), applied on the map.

For determining in flight the magnetic bearing of the VOR radio beacon relative to the aircraft position (Fig. 72) it is necessary to complete the following operation:

turn on the VOR-ILS equipment and wait 2-3 min, until it is warmed up thoroughly;

set the radio beacon frequency on the control panel;

listen to the call sign of the radio beacon;

by rotating the rack and pinion on the bearing indicator - setting mechanism SR-32, match the double pointer with the single,

with this the single pointer should be located between the components of the double pointer and be parallel to them:

check whether the course pointer of the course and glide-path indicator is located in the center of the dial face and if necessary set it in the center of the small black circle, by rotating the rack and pinion on the bearing indicator-setting mechanism;

take the reading of the magnetic bearing of the radio beacon in the window of the counter of the bearing indicator-setting mechanism and lay the line of the taken MPR on the map.

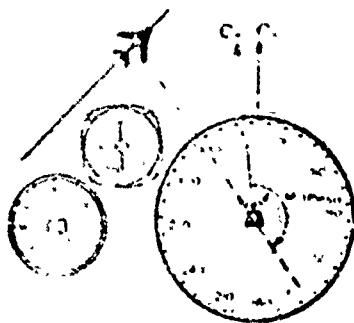


Fig. 72. The position of the pointers of SR-32 indicate when taking a reading of the radio beacon bearing.

When using the SR-34/35 equipment the magnetic bearing is read to the RMI or, by cranking the setting of the ZMPU on the azimuth selector, the settings of the vertical pointer on zero are attained on the course and glide-path indicator; then in the window of the azimuth selector it is possible to read the MPR if the "TO-FROM" pointer is in the "TO" position.

Note. In flight using the VOR system it is necessary to remember that the bearing to the radio beacon does not depend upon the aircraft course. This distinguishes the VOR system from the "radio compass - homing station" system, during the operation with which the bearing is obtained as the sum of the course and angle of approach of the radio station.

Flight to VCR radio beacon along a given magnetic bearing.  
After takeoff the crew must:

turn on the equipment, set the radio beacon frequency on the control panel and listen to its call sign;

set the value of given MPR on the bearing indicator-setting mechanism (SR-32) or on the azimuth selector instrument (SR 34/35);

if takeoff was not performed in the direction to the radio beacon, then execute the maneuver for approach to the line of the given magnetic bearing of the radio beacon.

With the approach of the aircraft to the line of MPR the single pointer of the bearing indicator-setting mechanism will approach the double pointer (when using SR-32 equipment).

For precise approach to the line of the given MPR the crew should turn the aircraft at an advance point of the turn. When the aircraft will fly strictly along the line of the given MPR, the course pointer of the course and glide-path indicator will be located in the center of the instrument, and the single pointer will be set between the double pointer and will be parallel to it (when using airborne equipment SR-32).

Determining the moment of flight over the VOR radio beacon. During approach of the aircraft to the VOR radio beacon periodic falling of the blinker is noted. The course pointer of the course and glide-path indicator becomes more sensitive even with insignificant deviations of the aircraft from the specified track. The single pointer of the bearing indicator-setting mechanism also fluctuates from  $\pm 5$  to  $\pm 10^\circ$  to both sides.

When after flight over the beacon there is provided for following a route with the same course, 15-20 km from the moment

of flight past the radio beacon it is advantageous to maintain course by the course pointer of the course and glide-path indicator, but by the GPK (course system in the GPK mode).

At the moment of flight over the beacon is noted by the rotation of the pointer, which indicates the MPR, to  $180^\circ$ . This rotation, depending on the altitude and flight speed of the aircraft is accomplished in 2-3 s.

Flight from the VOR radio beacon. For accomplishing the aircraft flight in the given direction from the radio beacon it is necessary to:

1. plot the specified track on the map;

2. set on the map the value of the magnetic bearing of the profile to the given one of the characteristic reference points, and plot the track within limits of the range of the radio beacon;

3.  $+180^\circ$  to the obtained value of the MPR;

4. after takeoff turn on the VOR equipment, set the radio beacon frequency and listen to its call sign;

5. set the value of angle  $MPR + 180^\circ$  on the indicator of the bearing setting mechanism (SR-32) or on the azimuth selector instrument (SR-34/35).

Depending on the takeoff direction with respect to the heading from the beacon perform the maneuver for approach to the line of the given MPR (the track), which is noted by the arrival of the vertical pointer of the course and glide-path indicator to the vertical position.

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Perform flight along the specified track by the course and glide-path indicator, monitoring the value of the ZMPU by the readings of the single pointer of the indicator of the bearing setting mechanism (SR-32) or by the RMI (SR-34/35).

An example of flight to the beacon and from the beacon with SR-34/35 equipment is given on Fig. 73.

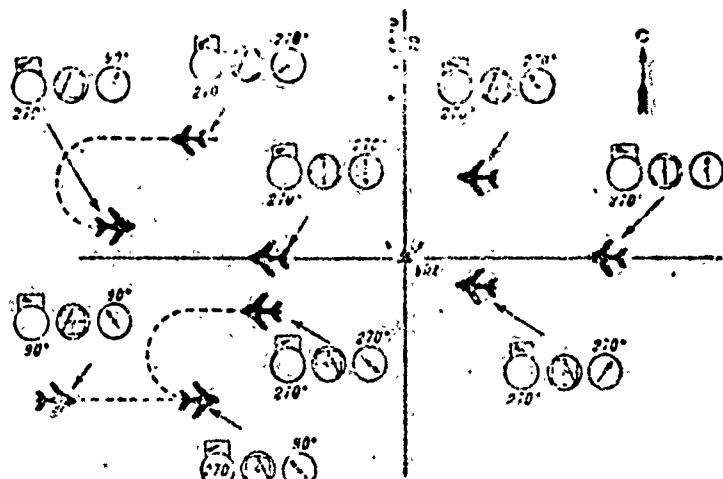


Fig. 73. Flights with SR-34/35 relative to VOR beacon.

Determining the aircraft position by the magnetic bearings of two VOR radio beacons is done with the greatest accuracy when flight is fulfilled "From" or "To" the beacon, and the second radio beacon is located abeam the right and left side of the aircraft. In this case the bearings of two radio beacons comprise an angle close to 90°.

For determining the aircraft position it is necessary to:

take the exact reading of the bearing of the radio beacon, which is lined up with the line of the given track, and plot it on the map;

to maintain the course by the GPK, time to the beacon located on the side of the aircraft track of aircraft flight, and take the bearing to the side radio beacon;

and the bearing line from the side radio beacon; the point of intersection of two bearings will be the aircraft position, if no correction for movement of the aircraft for the time of bearing on the map.

Knowing the time of flight and the distance between the marks on the map, it is possible to determine the ground speed of VOR radio beacons, and to determine the value of the ground speed.

After calculating the drift angle during flight along the line of approach to the side radio beacon ("To" or "From" it) is done

the following calculations:

$$MHD = MK;$$

the drift angle to the side radio beacon

$$MHD = MPR + (180^\circ) - MK.$$

Knowing the value of the MHD angle of more than  $180^\circ$ , during the calculation of the drift angle must be subtracted from the sum of  $MPR + 180^\circ$ .

Execution of the maneuver for entry into the zone of the radio-range beacon of the ILS system. With the aid of the VOR-ILS equipment it is possible to execute the maneuver of aircraft deviation, using the signals of the VOR radio beacon located at the airport, and perform entry into the zone of the radio-range beacon of the VOR system by the following methods:

with straight line;

along a large rectangular route;

by the method of normal blind turn or turning to the calculated angle.

The simplest maneuver of descent and entry into the zone of the radio-range beacon of the ILS system is executed when the VOR radio beacon is lined up with the line of landing.

In the case of straight-in approach with descent on the approach course to the airport the crew flies the aircraft using the signals of the VOR radio beacon by the course pointer of course and glide-path indicator until entry into the zone of coverage of the radio-range beacon of the ILS system.

During landing approach on the control panel instead of the VOR radio beacon frequency there is set the frequency of the ILS radio-range beacon. The entry into the zone of the ILS beacon is monitored by the lighting of the signal lamp with the label "ILS" and by operation of the blinker.

During landing approach along a large rectangular route by readings of the instruments of the VOR-ILS equipment the crew determines the moments of turns and entry into the zone of the ILS radio-range beacon. For this in the descent and landing approach procedure the values of the MPR of the reference points are calculated in advance. With agreement of the calculated and actual values of the MPR, taken from the bearing indicator, the moment of flight over these reference points is noted.

## TACAN ELECTRONIC SYSTEM

The operation of the TACAN system is different from the VOR system. The azimuth is determined by the TACAN system by means of radiation of a nondirectional signal and a rotating directed signal, the phase difference of which is proportional to the azimuth relative to the direction toward north. The carrier part of the TACAN system lies in the frequency range of order 1000 Hz. A rotating directed signal with variable phase is obtained by means of the mechanical rotation of the elements of the antenna.

Furthermore, cardioid with variable phase, rotating with frequency 15 Hz, is modulated additionally by a signal with frequency 135 Hz, whose phase is also compared with the signal of standard phase.

The result of this comparison makes it possible to obtain a ninefold increase in the azimuth measurement accuracy.

The TACAN system consists of AN/URN-3 ground equipment and AN/ARN-21 aircraft device, allows continuously and automatically determining the aircraft polar coordinates (azimuth and range) aboard the aircraft. The polar coordinates of the location of the aircraft are determined aboard it with high accuracy, which makes it possible to use them for introduction into special computers and the solution of various navigational problems, such as, for example, the flight of aircraft along any rectilinear routes, along orbits, etc.

Basic performance data of the system  
Operating range of frequencies,  
MHz..... 962-1213  
Accuracy:  
with respect to azimuth..... 1-2°  
(operational)  
with respect to range.....  $180 \text{ m} \pm 0.25\%$   
the distance

The range of action depends upon the flight altitude of the aircraft and lies within the direct geometric visibility.

The "dead" funnel with respect to the azimuth has a magnitude on the order of 95-100°.

The influence of terrain features on the accuracy of the system is considerably reduced as compared with the VOR beacon because of the use of decimeter wave band, pulsed operating conditions, and also a special nine-lobe radiation pattern of the antenna in horizontal plane. The ranging of the aircraft from TACAN ground installation proceeds in the usual way, by the "interrogation-response" principle, based on timing the propagation of the pulse radiated by the aircraft interrogator, and by its return back to the aircraft receiver from the ground installation of AN/URN-3 equipment.

The emission of azimuth information to the aircraft is accomplished because of the presence of a special antenna in the ground installation, creating a radiation pattern in horizontal plane in the form of a cardioid, rotating with constant frequency 15 Hz. As a result of the rotation of this cardioid the pulses radiated by the ground device on the aircraft undergo space amplitude modulation with frequency 15 Hz, whereupon the phase of this modulating frequency, which is the envelope of the received signals, will be proportional to the aircraft azimuth.

By measuring with the aid of the aircraft device the phases of modulating frequency 15 Hz with respect to the phase of the reference signal, we obtain data about the aircraft azimuth. As reference signals there are used pulses radiated by the ground device at the moment when the maximum of the radiation pattern (cardioids) of its antenna system passes through north, in connection with which the reference signals are frequently called "northern" reference signals.

The method of measurement of the azimuth, expounded above, is used only in the so-called coarse channel of the azimuth. For the achievement of higher measurement accuracy of the azimuth on the order of  $1^\circ$  the cardioid directional characteristic of the ground beacon antenna with the aid of additional modulation with frequency 135 Hz is converted into a nine-lobe cardioid, which ensures the obtaining of a second precise channel of measurement of the azimuth.

#### VORTAC ELECTRONIC SYSTEM

The name VORTAC is formed by the unification of the two names VOR (VHF omnidirectional radio beacon) and TACAN (tactical air navigation). The indicated combination provides azimuth determination according to VOR beacons on VHF and using the TACAN system on UHF.

The range is determined by the TACAN system on UHF.

#### DME AIRBORNE EQUIPMENT

The airborne DME equipment, designed for ranging from the aircraft to the ground radio beacon (in miles), during flight to the beacon and from it makes it possible to directly determine the ground speed of the aircraft (in knots), and during operation together with VOR, VORTAC and TACAN radio beacons provides the determination of the aircraft position.

The operating principle of the system (Fig. 74) is based on measurement of the time interval between the moments of sending the interrogation pulse from the aircraft and of obtaining the response pulse from the ground radio beacon. This time is directly proportional to the distance from the aircraft to the radio beacon.

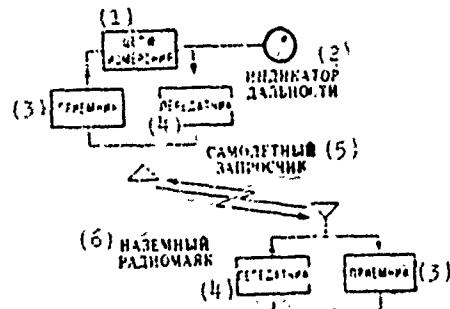


Fig. 74. Operating principle of the DME system.

KEY: (1) Measurement circuit; (2) Range indicator; (3) Receiver; (4) Transmitter; (5) Aircraft interrogator; (6) Ground radio beacon

Basic performance data of the system

The operating range of the system .....	196 nautical miles
Number of channels.....	100
Measurement accuracy.....	0.2 nautical miles, or 0.4% of the range
Receiver sensitivity, dB.....	90 (minimum)
The frequency range of the transmitter, MHz.....	1040-1150
The frequency range of the receiver, MHz.....	987-1213
Time of channel selection.....	not more than 3
Memory time.....	range readings are retained 8-12 s after loss of the signal
Standby mode.....	equipment automatically goes to standby mode with drop of power of the radio beacon signals
Self-checking mode.....	functional test. When pressing the knob on the front panel of the interrogator equipment the range, equal to 196.1 nautical miles should work
Synchronization and tracking...	the equipment follows changes in range at speeds up to 800 knots

Identification signals.....	with frequency 1350 Hz are fed to the telephone outlet with volume control on the control unit
Blanking.....	on the front panel of the interrogator there is a jack, through which goes the supply of "To" and "From" blanking pulses of the dis- patcher's interrogator- responder
Range resolution.....	<u>±0.1</u> nautical mile

The airborne equipment includes:

the interrogator, which includes the transmitter, receiver and range measuring circuit. On the front panel of the interrogator there is a knob for functional checking of the equipment;

the transceiving antenna, which is placed, as a rule, on the bottom of the aircraft fuselage;

the control unit is designed for turning on the equipment, setting of frequency, which corresponds to the channel number, operating mode switch and volume control of the call sign of the beacon.

On the panel of the unit (Fig. 75) are arranged:

digital counter 1 with the label "FMI,"\* intended for setting the frequency, corresponding to the channel number, on which the selected beacon operates;

---

\*[Translator's note: Original document has both DME and DMI, but believe they are referring to the same thing].

three coaxial knobs (small 3, medium 4 and large 5), designed for turning on the equipment and volume control of the call signals of ground beacons. Small knob 3 with the label "VOR" serves for turning on the equipment and for volume control of the call signals. Medium 4 and large 5 knobs are intended for setting the frequency on the digital counter 1;

the function selector 6, which has two positions: "STBY" - standby and "DMI" - ranging.

With setting of the switch in the "STBY" position the equipment is turned on and ready for operation, but the mechanism for the range indicator does not rotate and the red flag covers the numerals of the three-digit counter (Fig. 76).

With setting of the switch in the "DMI" position the equipment goes into the operating state, the red flag of the digit

counter is moved away and in the openings of the counter the current range to the beacon in nautical miles is read.

Range and ground-speed indicator. On the face of the indicator (see Fig. 76) are arranged:

knob 1 for setting on scale 2 the distance to the beacon or to any selected reference point

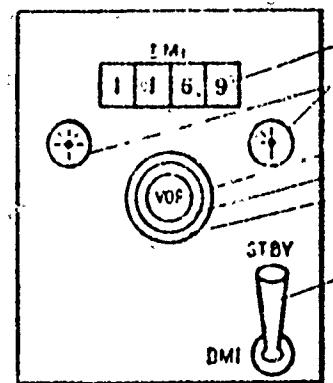


Fig. 75. Control unit of the airborne equipment of DME.

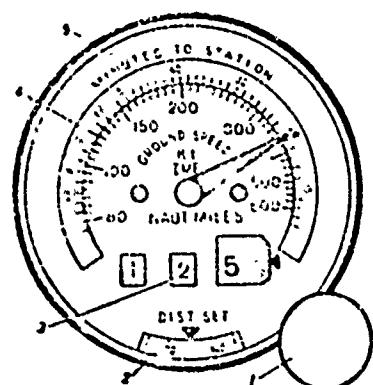


Fig. 76. Range and ground-speed indicator.

when determining the remaining flight time to this point (or beacon);

scale 2 for reading the range, set by knob 1; the scale is enumerated in nautical miles; scale value - 10 nautical miles;

three-digit counter 3, which shows the current value of range to the ground beacon in nautical miles; scale graduation - 0.2 nautical miles; with the equipment turned off or in search the counter is covered by a red flag;

inner fixed scale 4, serving for reading the ground speed, measured relative to the ground beacon within limits of from 80 to 600 knots (from 148 to 1112 km/h); scale graduation - 10 knots; reading - opposite the pointer tip;

outer slide scale 5 for reading the remaining flight time to the ground beacon or to any selected reference point; it is also read opposite the pointer tip of the ground-speed indicator; range of read off time from 6 to 20 min - in 1 min, from 20 to 100 min - in 5 min.

On the same panel, on which the control unit and indicator are located, there is placed a switch (Fig. 77), which has two positions: "ARK, SVOD, VOR" and "DME." It is designated for commutation of the telephone outlets to the SPU when listening to the call signals of beacons.

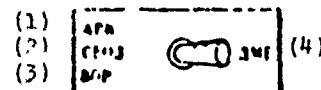


Fig. 77. Switch of call signals.  
KEY: (1) ARK; (2) SVOD; (3) VOR; (4) DME.

#### Preparation of the Equipment for Operation

1. On the AZS panel place the switch with the label "DME" in the "On" position.

2. Turn clockwise the small knob 3 (see Fig. 75) on the control unit and after the click place it in the intermediate position.

3. On the control unit by knobs 4 and 5 set the frequency which corresponds to the number of the channel of the beacon, in the working zone of which the aircraft is located.

4. Place switch 6 on the control unit in the "DME" position.

In 1-2 min the equipment goes to search. With this the drums of the digital indicator begin to whirl rapidly, but the red flag of the failure indicator signal covers the apertures of the indicator. With adjustment of the precise value of range on the indicator the equipment goes into the tracking mode and the flag of the failure indicator signal covers the numerals, which slowly pass in the apertures as the range changes. The duration of the search cycle is about 5 s.

The equipment does not leave the tracking mode during brief disappearances of response signals, but goes into the "memory," mode lasting about 10 s, retaining during this the last value of range. If after 10 s the signal is not located, the flag of the failure signaling covers the numerals of the counter and the equipment goes to search. In this case, if there is a useful signal, the digital drums under the flag whirl rapidly. With the absence of useful signal the numerals of the range indicator under the flag remain stationary and the equipment automatically goes to standby mode.

5. In order to check the correctness of selection of the ground beacon by listening to its call signals, it is necessary to:

place the call signal switch (see Fig. 77) in the "DME" position;

place the switch on the subscriber's SPU set in the extreme left position "ARK, SVOD."

After this in the telephones the call signals of the beacon, transmitted by international code with interval of approximately 30 s should be heard. After hearing the call signals of the beacon the switch of the call signals must be placed in the "ARK, SVOD, VOR" position.

With the appearance of doubt of the reliability of operation of the system it is necessary to check its efficiency by pressing the built-in monitoring knob on the front panel of the interrogator. With the equipment operable on the indicator will be worked out the range, equal to 196.1 nautical miles.

The equipment is shut off by counterclockwise rotation of the small knob with label "VOR" to the click on the control unit and by switching the AZS of the "DME" on the pilot's AZS panel to the "Off" position.

#### Working with the DME Equipment in Flight

In connection with the installation of KURS-MP-1 equipment on civil aviation aircraft, working with the VOR azimuth beacon, the use of the DME system should be considered in conjunction with the equipment indicated above.

For working with VOR-DME and VORTAC azimuth and range systems, and also with the TACAN system, which ensures only the delivery of the azimuth to obtain the MS, it is necessary on the control units of the DME system and KUPS-MP-1 equipment to set the frequency (channel) of operation of these beacons. In this case to the radiomagnetic indicator (RMI) the KURS-MP-1 will send the magnetic radio bearing to the beacon, and to the DME range indicator - the slant range to it.

When the aircraft is at a great distance from the beacon, the difference between the slant and ground range is very small, but as the aircraft approaches the beacon this difference increases. When the aircraft is located above the beacon, the ground range will be equal to zero, and slant - to the flight altitude shown in nautical miles. Since the ground speed is determined by measurement of the slant, and not ground range, the error in determining the ground speed is proportional to the error in determining the ground range.

In the set with the azimuth systems the DME equipment provides the solution of the following problems:

determining the aircraft position;

determining the ground speed and remaining flight time to the radio beacon or to any selected reference point;

approach to given point for descent;

flight in the holding area;

orbital flight;

bypass of dangerous zones.

**Determining the aircraft position.** For determining the aircraft position from the radiomagnetic indicator (RMI) of KURS-MP-1 equipment it is necessary to take magnetic bearings of aircraft (MPS) from the ground beacon, read on the inner dial face opposite the blunt pointer tip. Having introduced correction to the MPS, equal to the magnetic declination of the point of location of the ground beacon, determine the true bearing of the aircraft (IPS), which is read from the northern direction of the true meridian, passing through the point of installation of the beacon.

The intersection of the plotted line of the true bearing and the circumference, equal to slant range  $S$ , gives us the MS (Fig. 78).

In order to decrease the errors in determining the MS by the VOR-DME, VORTAK or TACAN system, by the last reading from two

magnitudes (range or MPS) one should take the one which for the same time unit undergoes a large change.

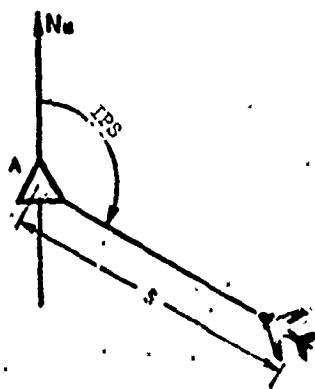


Fig. 78. Determining the MS by the VOR-DME.

In view of the number of errors permissible by RMI in the readings of the bearing, in determining the MS by this method considerable errors are also possible. Therefore for the most precise taking of the reading of magnetic bearing of the aircraft one should

use the azimuth selector of KURS-MP-1. This is executed in the following order: with the aid of a handle and flag, located on the azimuth selector of the KURS-MP-1, we set the value of the MPS, taken from the RMI. While continuing to rotate the knob on the selector, we set the vertical (course) lath of the null instrument in the center of the cross-hairs and on the azimuth selector we read the precise value of the magnetic bearing of the aircraft (MPS).

Determining the ground speed and the remaining flight time to the radio beacon or any selected reference point. During flight to the beacon and from it the ground speed is calculated automatically in the DME equipment and is indicated by a pointer on the range indicator on scale 4 (see Fig. 76) in nautical miles per hour (in knots). For determining the remaining flight time to the beacon it is necessary on scale 2 by knob 1

to set the distance, equal to the slant range to the beacon, taken from digital counter 3. Opposite the ground speed pointer on the outer scale 5 of the range indicator take the reading of the remaining flight time to the beacon.

On scale 2 it is possible to set the distance to any reference point, arranged on the route or abeam it, and with respect to these distances and there is read the time remaining to flight past the reference point.

Approach to a given point for the beginning of descent, entry into prelanding maneuver or for some other purpose is ensured by the repeated determining of MS, by correction of the direction and flight conditions according to the obtained data.

Flight in the holding area is applied in very rare cases mainly because of the overloading of the airfield zone by other aircraft. Usually this is a maneuver in the corridor of the air route, leading to the landing airfield. The dimensions of the maneuver are assigned by the minimum permitted range of airport approach and by the maximum permitted distance from it (taking into account the magnitude of turning radii).

Most often this maneuver is executed either directly above the VOR (or OPRS) beacon, or in its immediate vicinity (Fig. 79).

In this case flight along the first straight line until the turn is executed to the beacon or from it according to the null instrument. The radio bearing of the beacon in this case is set on the azimuth selector of the KURS-MP-1. The range reading at the assigned distance from the

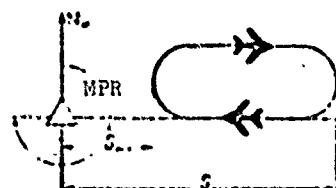


Fig. 79. Flight in the holding area.

beacon is performed by the DME range indicator. After turning 180° the aircraft follows the MPU, opposite that which it held on the first straight line, taking into account the wind, specified earlier.

In the case when the holding area is moved away from the VOR beacon to a considerable distance, flights along both straight lines can be performed by the null instrument in the modes to the beacon and from it, since with this the nonparallelism of both straight lines will be low enough to disregard it. Thus, at a distance of 57 km the IPU on both straight lines will differ by only  $1^\circ \pm 180^\circ$ .

Orbital flights around the beacon are used for dispersal of the aircraft in the airfield zone, when awaiting instructions about the accomplishing of the landing approach maneuver. In this case the aircraft follows the beacon along the established corridor of the air zone and with approach to the beacon at a distance equal to the assigned orbit taking into account the LUR executes a turn and enters the orbit. Further, while maintaining the assigned distance to the beacon by the range indicator of the DME the aircraft performs orbital flight. Usually from considerations of safety each aircraft is assigned its own orbit (Fig. 80).

**Bypass of dangerous zones.** For bypass of zones of thunder-storm activity and other dangerous meteorological phenomena it is necessary to know their location relative to the route, the direction of their movement and to determine the boundary of safe flight.

Bypass is performed along an orbit, while monitoring the distance by the range indicator (in flight to the beacon). During orbital flight on the azimuth selector of the KURS-MP-1 equipment the navigator sets the magnetic radio bearing of the

beacon, which one should fly along after bypass of the dangerous zone. After scaling of the course pointer by the null instrument one should perform a turn with approach to the assigned bearing.

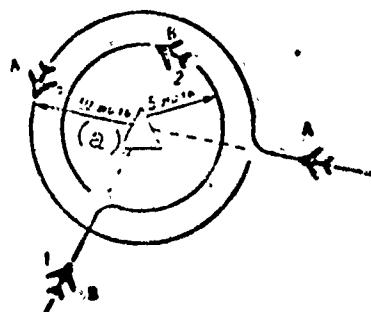


Fig. 80. Orbital flight.  
KEY: (a) Miles.

#### VRM-5 AND "CONSOL" SYSTEMS<sup>1</sup>

In the countries of the northern part of the Atlantic Ocean, on the shore of the Barents Sea sector beacons of the "Consol" and VRM-5 (USSR) system have been installed and continuously operate. For the reception of signals of VRM-5 and "Consol" radio beacons the installation of additional equipment on the aircraft is not necessary. The signals of the radio beacons can be received with the aid of a medium-wave receiver or radio compass. The signals of radio beacons can be used in flight only with the presence of special airborne maps with preplotted lines of bearings from the place of installation of the radio beacon.

The service range of the radio beacons, which operate on medium waves (200-400 kHz), depends upon the power of the ground radio beacon, the receiver sensitivity and the time of day. Antenna output of the operating radio beacons is from 1.5 to 5 kW, which makes it possible to pick up signals in the daytime with a receiver of medium sensitivity at a distance up to 1500 km.

<sup>1</sup>Chapter is written by V. A. Belyatskiy

At night the range of radio beacons is increased because of the effect of reflection of the radio waves from the upper layers of the atmosphere, in this case the maximum range of signal reception reaches 2500 km. In these cases the accuracy of direction finding is lowered (Table 24).

Table 24. The range of radio beacons at different time of day.

Time of day	Path of radio waves	Range, km	Mean error, deg
Day	Straight line	500	Less than 0.5
	"	1500	1
Twilight	Straight line	70	Less than 0.5
	" and reflected	600	From 3 to 5
	Reflected	2500	From 0.5 to 3
Night	Straight line	100	Less than 0.5
	" and reflected	600	From 3 to 5
	Reflected	2500	From 0.5 to 3

The beacons emit unmodulated signals in the form of a certain combination of dots and dashes. For reading the true bearing of the aircraft it is necessary during the direction-finding cycle (1 min) to compute the quantity of dots and dashes heard in the certain sector, and by the quantity of these signals on a map find the line of position of the aircraft. The radiation pattern of VRM-5 and "Consol" system radio beacons is given in Fig. 81.

The cycle of operation of VRM-5 radio beacon

Identification signal of beacon (two letters), s.....	8
Pause, s.....	2
Nondirectional radiation ("long" dash), s.....	10

The cycle of opeation of VRM-5 radio beacon  
(Cont'd.).

Pause, s.....	5
Direction-finding mode, s.....	30
Pause, s.....	5
<hr/>	
Total.....	60 s

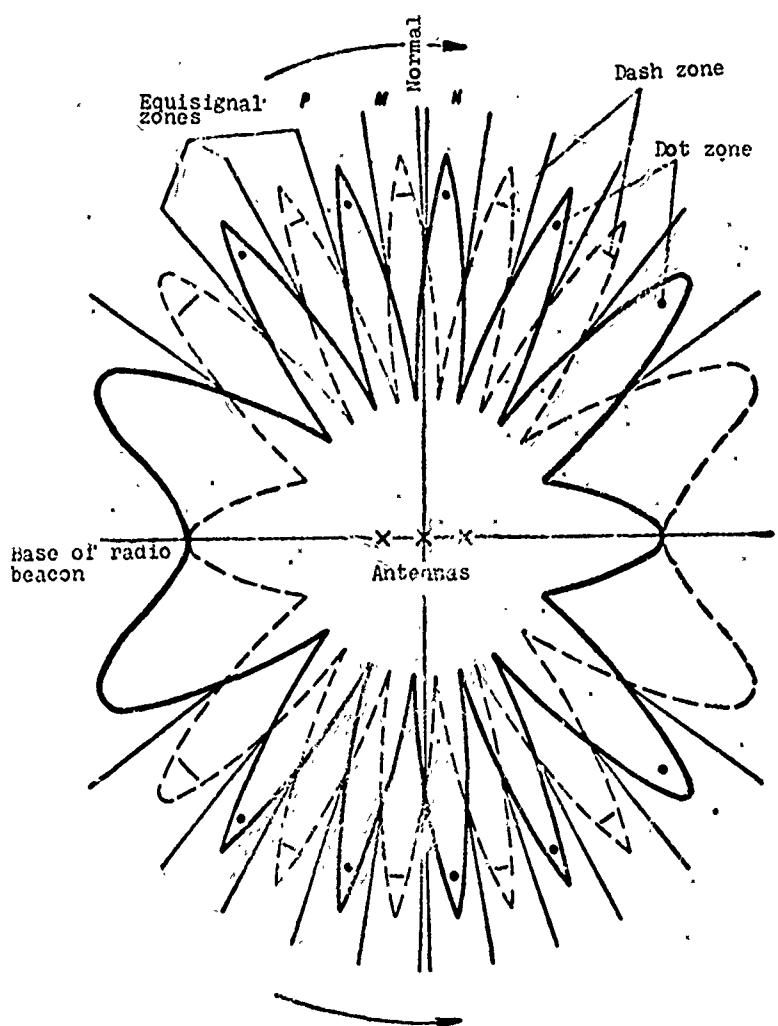


Fig. 81. Radiation pattern of radio beacons of the VRM-5 and the "Consol" system.

In radio beacons of the "Consol" system there is established a similar or reduced cycle of operation for 40 s. In the latter case nondirectional radiation is absent and the pauses are somewhat decreased. The direction-finding mode in all beacons is established at 30 s. The beacons of the "Consol" system are identified by two or three letters of the Latin alphabet. During operation of the beacon in the nondirectional radiation mode ("long" dash) it is possible to measure the KUP by an ordinary aircraft radio compass.

Determination of the bearing of the radio beacon is performed in the following manner.

1. On special radio navigation charts we mark those beacons which are heard during flight only in the sectors of reliable bearings.
2. We tune the receiver, identify the call signals of the radio beacon and the initial signals of the direction-finding mode (dots or dashes, radiated up to the equisignal zone).
3. By dead-reckoning position or approximate radio bearing of the IPS we determine the sector, within which the aircraft is located at a given period of time (permissible error of determining the bearing is  $\pm 10^\circ$ ).
4. We check that the initial signals of the direction-finding mode (dots or dashes, heard up to the equisignal zone) correspond to the signals designating the identified sector on the map.
5. During the direction-finding mode we listen to the quantity of dots or dashes of the equisignal zone (i.e., till the moment of disappearance of signals) and after the equisignal zone. The total amount of dots and dashes in every operating cycle should be equal to 60.

6. At the moment of hearing the equisignal zone we record the time of direction finding.

7. With the loss of a certain quantity of signs in the cycle both to the computed quantity of dots and to the computed quantity of dashes we separately add the half-sum of the quantity of lost signals.

Example. Before hearing the equisignal zone there are counted 18 dashes, and after the equisignal zone - 36 dots.

The total amount of received signals  $18 + 36 = 54$ .

The half-sum of the lost signals  $\frac{60 - 54}{2} = 3$ .

The corrected quantity of dashes will be  $18 + 3 = 21$ .

The corrected quantity of dots will be  $36 + 3 = 39$ .

The total corrected signals  $21 + 39 = 60$ .

8. The radio bearing is plotted on the map with respect to the quantity of corrected signals (dots or dashes), heard up to the equisignal zone, by means of linear interpolation between the multiple lines of radio bearings depicted on the map. For the given example the lines of the bearing correspond to 21 dashes and it should be drawn in the sector of dashes between lines 20 and 25 (Fig. 82).

The aircraft bearing can be determined by the measurement of the individual periods of the direction-finding mode of the radio beacon by a stop watch. If we designate  $n_1$  - number of signals to the equisignal zone, and  $n_2$  - number of signals after the equisignal zone, then

$$n_1 - 2\tau_1 + \tau_p; n_2 = 2\tau_2 + \tau_p.$$

where  $\tau_1$  - the listening time of the radio beacon signals to the equisignal zone, during which  $n_1$  signals are emitted (dots or dashes);

$\tau_p$  - the listening time of the equisignal zone;

$\tau_2$  - the listening time of the signal zone, during which  $n_2$  signals are emitted (dots and dashes),

whereupon

$$\begin{aligned}\tau_1 + \tau_p + \tau_2 &= 30 \text{ s;} \\ n_1 + n_2 &= 60 \text{ signals.}\end{aligned}$$

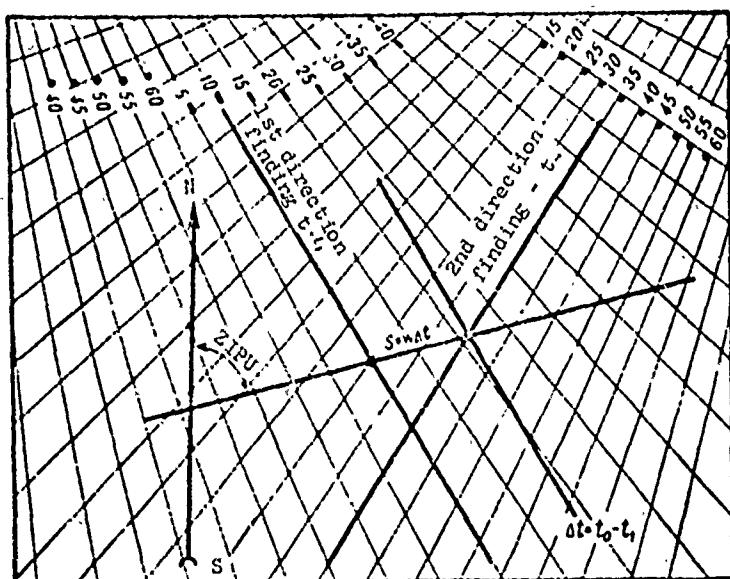


Fig. 82. Determining the aircraft position.

Using this method, it is possible to determine the aircraft bearing without listening to the entire direction-finding mode, since the quantity of lost signals is determined with the time of listening to the equisignal zone.

The order of measurements is the following:

- 1) at the moment of the beginning of the direction finding mode activate the stop watch;

2) at the moment of signal fading note the time in seconds;

3) at the moment of the beginning of hearing the other signals stop the stop watch;

4) by the conducted readings of time find  $\tau_1$  and  $\tau_p$  and from them - the quantity of signals of the radio beacon to the equisignal zone  $n_1$ .

Table 25. Data of VRM-5 and "Consol" radio beacons.

No.	Radio beacon	Place of installation	Coordinates		Frequency, kHz	Call sign	Cycle of operation, s	Air route, on which signals are heard in the daytime
			longitude	latitude				
1	Kanin	P-ov Kanin (USSR)	-	-	263	KN	60	Murmansk - Petrozavodsk. Vologda - Arkhangel'sk - Nar'yan - Mar Barent Sea
2	Rybachiyy	P-ov Rybachiyy (USSR)	-	-	363	RB	60	
3	Stavanger	Stavanger (Norway)	05°38' E. Long.	58°38' S. Lat.	319	LEC	66	Copenhagen - London North sea
4	Bushmills	Bushmills (N. Ireland)	06°23' W. Long.	55°12' S. Lat.	266	MWN	40	Amsterdam - London - Reykjavik
5	Ploneis	Ploneis (France)	14°14' W. Long.	48°01' S. Lat.	257	TRQ	40	London - Paris - Brussels
6	Lugo	Lugo (Spain)	07°23' W. Long.	43°14' S. Lat.	285	LG	-	-
7	Seville	Seville (Spain)	06°02' W. Long.	37°31' S. Lat.	315	SL	-	-
8	Nantucket*	South of Boston (USA)	70°09' W. Long.	41°16' S. Lat.	194	TUK	-	New York - Greenland
9	Atlantic City*	Atlantic city (USA)	74°46' W. Long.	39°07' S. Lat.	516	ALY	-	New York - Greenland

\* Station of the "Consol" system.

Example. The listening time of the dots of the beacon  $\tau = 12$  s. The listening time of the equisignal zone, i.e., the

time from the moment of disappearance of dots to the moment of beginning of hearing the dashes,  $\tau_p = 4$  s.

The corrected quantity of dots will be equal to

$$n_1 = 12 \times 2 + 4 - 2 = 28 \text{ dots.}$$

By this magnitude in the zone of dots it is possible to read the true bearing of the aircraft (IPS).

#### BASIC FEATURES AND PURPOSE OF ELECTRONIC DIFFERENCE-RANGING NAVIGATION SYSTEMS

The differential ranging systems of long-range navigation belong to the systems which measure the propagation time of radio waves from two fixed points on the earth's surface - ground stations of the system - to the aircraft. By the measured difference of radiowave propagation there is determined the difference of distances to ground stations and the line of position of the aircraft.

With the presence of two pairs of ground stations there are determined two lines of position, the intersection of which is the aircraft position (MS).

Pulsed differential ranging systems make it possible to solve the following navigational problems:

- a) monitor the path by determining the line of position or aircraft position;
- b) guide the aircraft to the assigned area;
- c) determine the navigational elements of flight.

In the examined systems the lines of position of the aircraft are two hyperbolas and therefore the systems also carry the name of hyperbolic systems.

It is natural, that to obtain two lines of position it is necessary to have two pairs of transmitting stations. However, the ground equipment of the hyperbolic system can consist altogether of only three stations, of which one A is the master station for both pairs (A-B and A-C), and the two others (B and C) - slave (Fig. 83).

Three ground stations A, B and C form two bases AB and AC. The bases, arranged in such a version of mutual orientation, are called combined bases.

Other versions of mutual orientation of bases are possible. Bases can be spaced (Fig. 84a), intersecting (Fig. 84b), combined in twos and threes (Fig. 84c, d) or arranged in a chain (Fig. 84e), in which several stations are master.

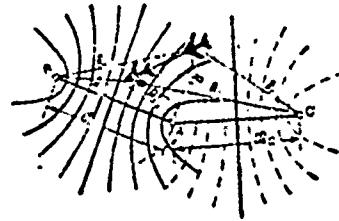


Fig. 83. Line of position of hyperbolic system.

The operating principle of the hyperbolic system is reduced to the determination of the time interval  $\Delta t$  between the reception of pulses on the aircraft, which the master ground station A and one of the slave stations - B or C emit (see Fig. 83). To this time difference corresponds the completely determinate difference of the distances from stations A and B (or C):

$$\Delta R = \Delta t c,$$

where  $c$  - the speed of light.

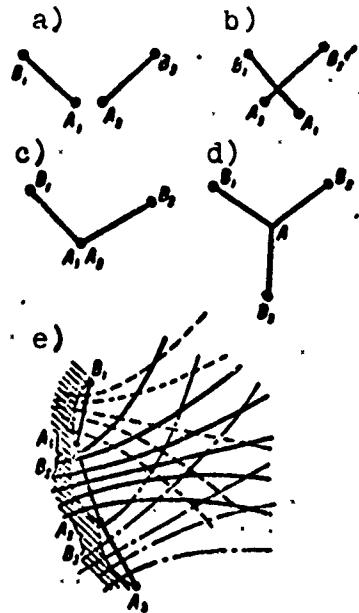


Fig. 84. Versions of mutual orientation of bases.

The hyperbola is a locus, the difference of distances of which from the focuses of hyperbolas is a constant value. The hyperbola, in the focuses of which are located the ground stations of the system, is the line of position. It is determined with the aid of a receiving-indicating device, which is located on the aircraft with respect to the measured time difference  $\Delta\tau$ . The second line of position is determined from a second pair of stations.

Navigational problems are solved on a special map with lattices of hyperbolas, plotted with respect to points calculated with the aid of geodesic formulas.

With movement of the aircraft in space along some lines of position the measured time difference of arrival of pulses at the aircraft from master and slave stations  $\Delta\tau$  remains constant. If air navigation is accomplished at comparatively short distances within 1000 km, then the curvature of the earth's surfaces does not have considerable influence on the character of the lines of position and it can be disregarded. In this case the lines of position will be the family of hyperbolas.

The points of arrangement of ground stations at points A and B are focuses, and the measured differences of distances -

real axes. If both stations A and B emit signals simultaneously, then the line of position, on which  $\Delta t = 0$  will be the hyperbola, degenerated into a straight line, perpendicular to the base in its middle (Fig. 85).

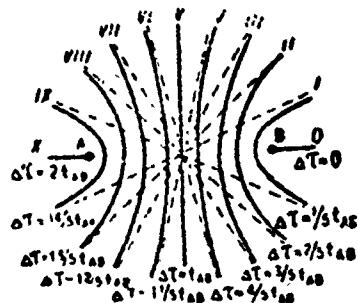


Fig. 85. Change of value  $\Delta t$ .

With departure of the aircraft from this straight line - "zero" hyperbola to the left - the pulses from station A will enter the receiving-indicating

device of the aircraft earlier than the pulses being sent by station B, whereas with movement of the aircraft to the right of the "zero" hyperbola the pulses from station B reach it earlier than pulses from station A. If with deviation of the aircraft to the left the measured interval is considered positive, and with deviation to the right - negative, then naturally interval  $\Delta t$  will reach the greatest absolute value when the aircraft is located on the straight line, being a continuation of the base, beyond station A or beyond station B. Under the condition that to the left of the "zero" hyperbola the measured time difference  $\Delta t$  is considered positive, and to the right - negative, on the continuation of the base to the left of point A  $\Delta t = +t_{AB}$ , and to the right of point B

$$\Delta t = -t_{AB} = -\frac{d}{c},$$

where  $t_{AB}$  - the time of passage of base AB by the radio waves; d - base of the station; c - propagation velocity of radio waves.

Since the measured interval  $\Delta t$  can be changed from  $+t_{AB}$  to  $-t_{AB}$  and the pulses of station A and B do not differ from one another at all, the reading is obtained ambiguous and there is no

possibility of determining whether the aircraft is located to the right or to the left of the "zero" hyperbola, for example, on hyperbola I or on hyperbola II.

In order to avoid this ambiguity of reading, the pulses of one of the stations should be emitted with delay relative to the moment of radiation of pulses by another station to some time interval ( $t_{AB}$ ). Then at all points of the operating region of the system the pulses of the first station will be received earlier than the pulses of the second station and the magnitude  $\Delta\tau$  will always be positive (with the exception of points on the continuation of the base after station B, where  $\Delta\tau = 0$ ). After station A  $\Delta\tau$  will be greatest:

$$\Delta\tau_{\max} = 2t_{AB} = 2 \frac{d}{c}.$$

In order to make the numbering of hyperbolas convenient in practical operation, especially when accomplishing interpolation between hyperbolas, at the slave stations there are introduced delays ( $t_0$ ), which supplement readings according to the applied hyperbolas up to values, multiples of ten.

Furthermore, at slave stations there are introduced additional so-called code, delays which increase the reading by magnitude  $t_K$ .

This magnitude ( $t_K$ ) is considered automatically in the aircraft receiver-indicator of the system.

The matching of operation of the stations is accomplished in the following manner: master station A controls the operation of slave station B, which emits pulses after the reception of signals from the master station, i.e., with delay equal to  $t_{AB}$ . By this the synchronous operation of both stations is attained. However, the slave station does not emit signals

precisely at the moment of the arrival of pulses from the master station, but with some delay. This delay has two components: constant  $r_0$  and variable  $t_h$  - code delay. The first is introduced so that with reception on the aircraft it would be possible to distinguish the pulses of station A from the pulses of station B.

The second delay serves for change of the numbering of the lines of position (hyperbolas) according to certain regulations.

The time interval of reception of signals from stations A and B, measured on the aircraft, is equal to  $\Delta\tau_1 = \Delta\tau + t_0 + t_h$ , where  $\Delta\tau$  varies from 0 to magnitude  $\Delta\tau_{\max} = 2t_{AB}$ .

Thus, a system consisting of one pair of stations does not make it possible to determine the MS, since by one base there is determined only one line of position.

For determining the MS it is necessary to use two pairs of stations (or three stations, of which one is overall master), arranged in such a way that the lines of position of the first and the second pairs would intersect (see Fig. 83).

On the reading mechanisms of the aircraft receiver-indicator there is read the numbers of hyperbolas - the lines of position.

The aircraft position can be determined on the entire area, where the signals of ground stations are heard, with the exception of the nonworking zones, which are arranged on a focal axis, beginning from focuses in the direction opposite the "zero" hyperbola. The nonworking zones are limited by the first branches of the hyperbolas of a given family.

In practice the accuracy of the system is different in different directions. Near the perpendicular, drawn through

the middle of the base, the accuracy is the greatest, but it drops in proportion to the distance from this perpendicular and near the line, which is a continuation of the base, it is so low that the system here cannot be used in practice.

Generally differential ranging radio navigation systems provide high accuracy of determining the position of a moving object and at the same time with rationally selected wave band have long range. In connection with this the given systems are used basically as long-range navigation means.

The version of the arrangement of the system, at which the stations form a chain, stretched along the coast line, facilitates navigation in the area of a large water basin. Therefore the hyperbolic systems received wide distribution during the development of transoceanic flights.

Another advantage of these systems is the unlimited capacity and the absence of a transmitting device on the aircraft.

Deficiencies of the system can be considered the complexity and the unwieldiness of ground equipment, and also the necessity of strict maintaining of synchronism of operation of the stations.

#### PRECISION HYPERBOLIC LONG-RANGE NAVIGATION SYSTEM "CYTAC" ("LORAN-C")

In the international organization ICAO as a standard means of long-range navigation the "Loran" system of long-range navigation was accepted a long time, ensuring the coverage of long distances, especially the air lines which lie over sea spaces.

The "CYTAC" system (development of USA) is a further development of the "Loran" system and facilitates determining the aircraft position with even considerably greater accuracy. The

high accuracy is attained because of the phase method of comparison of the transit time of signals from ground stations. In the "Loran" system the pulse train is transmitted with standard repetition frequency (from 20 to 60 Hz), while in receiver the time is measured between the reception of the impulses of separate stations. To obtain the greatest accuracy in determining the time interval between the pulses, incoming from the separate stations of the chain, in the receiving equipment of "CYTAC" ("Loran-C") there is additionally performed comparison of high-frequency duty factor of the pulse train of master and slave stations. The accuracy of the "CYTAC" system therefore is many times higher than "Loran." The range of the "CYTAC" system is also considerably greater than the "Loran" system.

The operation of the "CYTAC" system is similar to the "Loran" system. The first ground station, called master, transmits the pulse, following which in a definite and known time interval (interval  $T$ ) follows the second pulse, transmitted from the second ground station, located at some distance from the first. Both the signals from these stations will be accepted by the aircraft receiver with the same interval if the stations are located at equal distances from it. If the aircraft is closer to the first station, then the time interval will be greater by magnitude  $\Delta T$  ( $T + \Delta T$ ). If it is closer to the second station, then the interval between pulses will be smaller by magnitude  $\Delta T$  ( $T - \Delta T$ ). By measuring the interval between the two pulses and comparing it with a known interval, the airborne receiver determines the line passing through the point of location of the aircraft. This line is a hyperbola, the focus points of which are the points of location of the two transmitting stations.

If a pair of similar pulses is transmitted by a pair of different, differently arranged stations, one of which can be a part of the first pair, then the interval between the reception

of these two pulses makes it possible to establish the second hyperbola. The intersection of hyperbolas on the Loran-CYTAC chart will determine the MS.

If the third pair of stations operates, then the hyperbola obtained with their aid will serve for checking and refining the previous constructions. In actuality, in the chains of the "Loran" and "CYTAC" systems the master stations have two or three slave, with each of which these master stations operate on one frequency in turn and in a certain sequence.

For operation of the "CYTAC" ("Loran-C") system it is necessary that besides strict synchronization of the moments of radiation of pulses of the master and slave stations there would be synchronization of the phase of high-frequency duty factor of pulses. This is accomplished by the transmission of the appropriate signals by the master station on the carrier wave. Rough timing between pulses is performed just as in the "Loran" system, which makes it possible in the future to eliminate ambiguity during the precise determination of distances by the comparison method of phases of the high-frequency duty of pulses. Ambiguity can appear during the comparison of the phase of the first pulse of the master station with the second pulse of the slave station. Such a method makes it possible to measure the pulse separations to within 0.02-0.03  $\mu$ s. The resulting error in the measurement of the time interval of the "Loran-C" system is 0.1  $\mu$ s instead of 1  $\mu$ s of the "Loran" system.

The operating experience showed that with the aid of this system the aircraft position can be determined in 25% of the cases with accuracy on the order of 250 m at distances about 1500 km from one of the three transmitters of the system.

When using a direct wave the system provides precise determination of the coordinates at a distance up to 2500 km in the daytime and up to 1800 km at night; when using an indirect wave the system can be used at distances up to 3200 km in the daytime and up to 4200 km at night with error on the order of 4-5.5 km.

#### THE DECCA-DECTRA SYSTEM<sup>1</sup>

Among the radio navigation systems used for air navigation, the phase long-wave hyperbolic system "DECCA" occupies a special place. The system provides sufficient accuracy of position finding for flights along air routes. It should be noted that the system is not free from electrostatic interferences and the quality of its operation in clouds, precipitation and in areas of thunderstorm activity is considerably lowered.

The areas served by the system are continuously expanded because of the actuation of new chains on the main international sea and air lines.

In the zone of coverage of one chain of the "DECCA" system there is located one master station and three slave. The slave stations are installed at an angle of approximately  $120^{\circ}$  and are called green, red and purple.

In the countries of Western Europe more than eight chains of the system are operating, serving about 2 million sq. miles. The chains of the system are installed on the territories of England, Denmark, West Germany, France, Spain and Italy. In North America and Canada more than four chains operate. Two chains of the system are used in India and on the coast of the Persian Gulf.

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<sup>1</sup>Chapter written by V. A. Belyatskiy.

The "DECCA" radio navigation system is a further development of the "DECTRA" [sic] system (Fig. 86). In it are used the ground equipment and receiver-indicator of the "DECCA." The "DECTRA" system is intended for use in transoceanic air and sea navigation along certain routes.

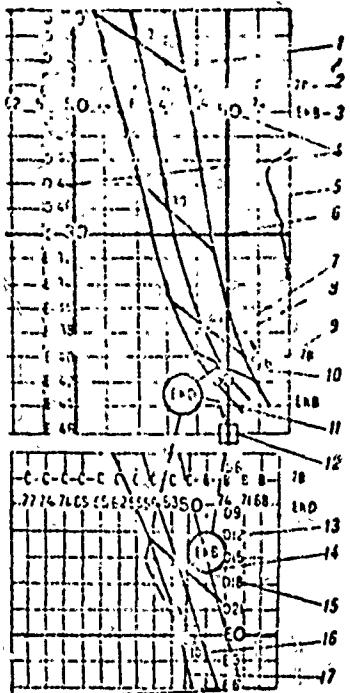


Fig. 86. The section of the chart of the "DECCA" plotting board:  
 1 - marks in nautical miles; 2 - station frequency; 3 - key of the chart section; 4 - readings corresponding to the indications of decameters; 5 - coast line; 6 - hyperbolas of zone boundaries, point of setting of stylus on the section of the route; 7 - boundary of route; 8 - assigned route; 9 - track angle; 10 - mark of the termination of recording on the chart and change of the chart key; 11 - key of the following section of the chart; 12 - point of setting of stylus after replacement of chart for the EKB key; 13 - hyperbolic grid of chart; 14 - key of the following section of the chart; 15 - mark of termination of recording on the chart and change of chart key; 16 - point of initial setting of the stylus for the EKD key; 17 - mark of change of the key and setting of stylus.

The operating principle of the system. Electromagnetic oscillations are characterized by amplitude, period  $T$  and frequency  $f = 1/T$ , or angular velocity  $\omega = 2\pi f$  and phase  $\omega t$ . The phase difference depends upon the difference of the time of passage of signals to the radio receiver. The aircraft receiver of the "DECCA" system compares the phases of the signals of the master station with the phases of the signals of the slave stations. For the chain of the "DECCA" system there are calculated the lines of different phase differences, which are hyperbolas,

conditionally designated on the chart by red, green and purple lines of position.

With the range of the "DECCA" system about 400 km the accuracy of determining the aircraft position lies from 100 m to 2-5 km. The range of action of the "DECTRA" system is approximately 2500 km, and the accuracy of determining the MS lies from 1.5 to 20 km.

**Application of the system.** The chains of the ground stations, which have certain frequencies given to them, are designated by a number and letter. For example, stations of the "DECTRA" system, serving the transatlantic line, are given the letter A, the group of European "DECCA" stations - the letter B, and American - C.

The airborne aircraft equipment includes:

"DECCA" and "DECTRA" receivers;

control panels of receiver and ground-position indicator;

indicators-decameters, "DECTRA" indicator;

ground-position indicator (FLIGHT LOG), unique for the "DECCA" and "DECTRA" systems.

computer unit, auxiliary units, antennas.

On the "green," "red" and "purple" decameters the numbers of the lines of position, plotted on a special chart in the form of green, red and purple hyperbolas, are read automatically. The point of intersection of two or three hyperbolas corresponds to the aircraft position.

In the "DECTRA" system special indicators give the direction to the master station and the distance to it, and the accuracy of the readings of the current range depends upon the correctness of establishment of the initial range. The initial range is determined with the aid of any other navigational system. If the aircraft is located in the range of the "DECCA" system, then for determining the initial range it is also possible to use the readings of this system.

The ground-position indicator considerably simplifies air navigation, by giving a visual representation of the aircraft position relative to the specified track.

The flight route will be plotted on a special route chart-plan, which moves on rollers of the plotting board of the ground-position indicator.

The route charts for the separate sections of the route are made with variable scales depending on the region of the working zone of the system, in which the given section of route lies, and on the selection of two pairs of hyperbolae, the intersection of which is close to 90°.

The track is traced on the route chart automatically by the moving stylus. For change of sheets of the chart and the correct installation of the stylus on the new sheet for each section of the sheet of the chart of the set of special keys it is necessary to select the necessary key, which is put into the computer.

On the chart there is faintly plotted the minimum geographical load (coastline, largest rivers and cities).

Special load includes:

given track angle;  
hyperbolic grid;  
the keys of the route sections;  
the readings which correspond to the indications of decameters;  
the place of initial setting of the stylus for the new key;  
marks of termination of recording and change of the chart key.

#### INERTIAL NAVIGATION SYSTEM

Inertial systems do not require external sources of information (ground stations, beacons, radar reference points, etc.). The systems themselves also emit no energy. Furthermore, they are not disturbed by any interference. Therefore they are the most self-contained systems.

The components of the inertial systems (Fig. 87) are such well known devices as accelerometers, gyroscopes, servomechanisms, computers. However, under conditions of large temperature drops, shocks, vibrations and considerable accelerations the use of these systems for navigation purposes became possible only when technology was able to provide for the highest accuracy of their manufacture and control, and consequently, the preservation of assigned parameters by them.

Principle of action. Mechanical energy of all bodies and parts, making up the aircraft, in flight is continuously changed

depending on changes in flight conditions, effects of the environment, etc. By determining the changes in mechanical energy by a special instrument, converting and recording them, it is possible to calculate the aircraft speed and the path being passed by it.

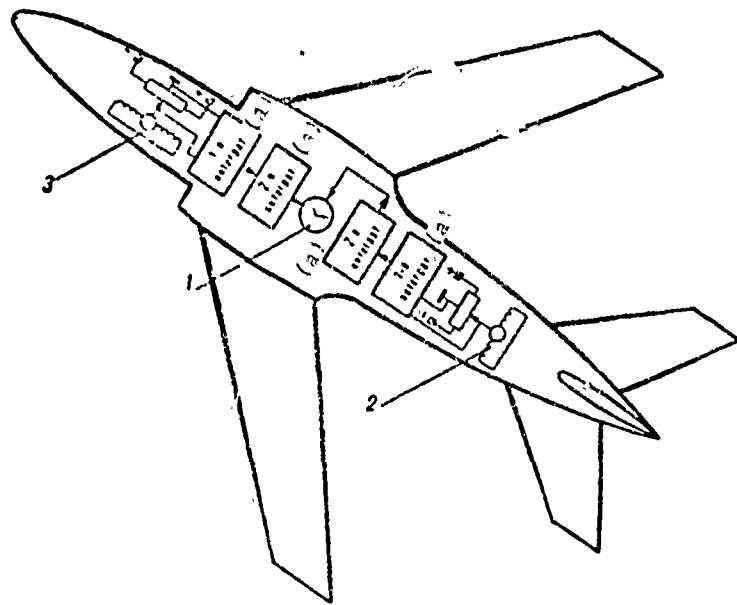


Fig. 87. Diagram of the inertial navigation system of the aircraft: 1 - air-position indicator (integrator); 2 - lateral accelerometer; 3 - longitudinal accelerometer.  
KEY: (a) Integrator.

Any body obtains acceleration under the action of force, whereupon the obtained acceleration is proportional to force affecting the body

$$F = m \cdot a,$$

where  $F$  - force;  $m$  - mass;  $a$  - acceleration.

The acceleration meters are called accelerometers. The simplest accelerometer is a weight with mass  $m$ , spring-mounted. If we place such a meter on a carriage, and to its weight attach

the slide of the potentiometer, fastened on this carriage, then with the carriage fixed the slide will stand motionlessly in the middle of the potentiometer and no potential difference will be observed. If to the carriage we apply force  $F$ , it will begin to move and weight  $m$  acquires acceleration  $a$ , as a result of which it will begin to shift relative to the platform (potentiometer) until force is counterbalanced by compression and elongation of the springs.

It is obvious that the amount of displacement of the weight (and the potentiometer slide) will be proportional to force  $F$ , and consequently, to acceleration  $a$  and the appearing potential difference, the sign of which depends upon the direction of acceleration.

If at the moment of application of force the speed of the carriage was equal to zero, then, by knowing the acceleration (according to the accelerometer), it is possible to calculate the speed acquired by the carriage in a certain time, and the path being passed by it during this time. For this integration is used.

Acceleration is the velocity increment in a unit of time:

$$a = \frac{dv}{dt}.$$

If we integrate the acceleration from the beginning of motion to moment  $t$ , then we will obtain the velocity of this moment. And by integrating the velocity, we will obtain the distance being passed by the carriage during this time:

$$v = \int_0^t a dt;$$

$$s = \int_0^t v dt.$$

Having placed on the same carriage (or aircraft) another

accelerometer with a small weight, moving not in the direction of motion, but perpendicular to it, it is easy to measure the acceleration which acts on the body in lateral direction.

By this acceleration we analogically calculate the lateral deviation of the body (aircraft).

Thus, it is possible in the orthodromic coordinate system with origin at the take off point of the aircraft to indicate its position relative to the LZP. For this to the pairs of integrators it is necessary to electrically connect the longitudinal and lateral accelerometers with sweep indicator, by which it is possible at any moment to read the magnitude of the track from the moment of start and the linear deviation from the given direction of motion.

Accelerometers. In the inertial systems basically linear accelerometers are used, intended for the measurement of linear accelerations affecting the body, i.e., the effects of only those forces which are directed along the measuring axis of the instrument. The action of the simplest of such accelerometers is based on the measurement of displacement of a cushioned mass.

Difficulties in the development of new accelerometers for air navigation purposes are connected with the range of accelerations (ratios of maximum and minimum accelerations). This ratio should be on the order of 100,000. For the accelerometer with cushioned mass with such a ratio of maximum and minimum measured accelerations in the case of low acceleration the operation of the instrument will be affected by friction forces, and with high accelerations errors will arise because of the dead zone and hysteresis of the elastic suspension. Even if the dead zone is 0.001 dyne, the error in dead reckoning per hour of flight will reach magnitudes up to 76 km.

One of the solutions to this problem is the use of an "electric spring." This device is based on motion of the mass of the accelerometer rod in a solenoid. During aircraft motion with acceleration to the amplifier input is supplied current of a certain voltage, which after amplification in proportion to the output value of amplifier current is supplied to the solenoid for counteraction to the movement of mass. After the initial acceleration during the motion of mass in the opposite direction there appears restoring current also of reversed direction. Thus, each movement of mass can be measured by voltage at the amplifier input or by the force of restoring current, which enters the solenoid.

Similar type accelerometers satisfy their sensitivity, which can be increased in almost the entire operating range.

Many similar devices are distinguished from one another only by the form of kinematic connection with the housing of the flight vehicle.

Gyrostabilized platform. For holding the platform with accelerometer or with the unit of accelerometers in horizontal plane there is used the property of a free gyroscope to maintain the position of the axis of its rotor constant in inertial space (relative to the stars).

The gyroscope with three degrees of freedom, not being subjected to the action of any moments of external forces, including friction forces, is called free. The center of gravity of such a gyroscope should coincide with the point of intersection of the axes of the gimbal.

The basis for the device of the gyrostabilized platform is the principle of power gyroscopic stabilization. With power

stabilization the gyroscopic moment compensates the harmful external moment, i.e., it is unloading only until precession occurs and the unloading moment of the motor (bearing in mind that on all three axes of the gyroscope unloading motors have been installed) reaches the necessary magnitudes. Subsequently the axis of the gyroscope is even unloaded because of the moment being created by the motor, but not because of the gyroscopic moment. The moment of the motor can be made quite large.

The stabilized platform, in this way, embodies the idea of a gyroscope with nonrotating rotor, which, however, keeps the position of the rotor axis constant relative to inertial space. All this makes it possible to use the power gyroscopic platform for stabilization of equipment of inertial navigation, radar antennas and a number of other devices in the horizontal plane.

Floating integrating gyroscopes. The stabilization of a platform with accelerometers with the aid of a unit of floating integrating gyroscopes acquires ever increasing distribution. While being very sensitive to angular displacements the platforms, which integrate the gyroscopes unlike power stabilization, while processing, do not create any unloading moment, but only supply the signals from their sensors to the unloading motors. Since these signals do not appear simultaneously with the application of external moment, but only after some deviation of the platform, there is observed a kind of fine jitter (vibration) of the platform about the mid-position. The rotor axes of the integrating gyroscopes are arranged parallel to the three axes of stabilization of the platform - in three mutually perpendicular planes.

The integrating gyroscope - gyroscope with two degrees of freedom - can be obtained, having eliminated the external frame

with the fluid damper. The name "integrating" results from the problem being solved by the gyroscope: during rotation of the platform keep the angle of turn of the frame proportional to the angle of rotation of the platform, i.e., to the time integral from the angular spin rate of the platform.

The floating integrating gyroscope is able to integrate angular velocities on the order of  $5 \cdot 10^{-5}$  rad/s (0.142 rpm), i.e., it is sensitive to the angular velocity approximately equal to one revolution in 1.5 days. At the same time it is in a state to integrate angular velocities greater than 4.5 rad/s, i.e., more than 42 rpm. Thus, the ratio of maximum to minimum speed of measurement is  $9 \cdot 10^4$ .

Since the integrating gyroscope in pure form is able to measure only the small angles of rotation of the platform, for the measurement of the large angles of rotation of the base it must be continuously turned with the aid of a servodrive.

Servodrive. In the inertial system the servodrive serves for providing the assigned geometric stabilization of the platform with any calculated position changes of the aircraft in air.

Since gyroscopes are capable of perceiving the smallest rotations around their input axes, and accelerometers - catching negligible accelerations, the servomechanisms should be very sensitive to the weak signals being sent by these instruments, and in answer to them turn the platform in the necessary manner. The speed of actions of the servomechanisms should be extremely great, and dynamic errors - small.

The components of servodrives, such as electromagnetic amplifiers, electrical servomotors and their reducers, which

were used earlier, satisfy the requirements for the necessary accuracy, linearity, small time constants and good dynamic characteristics. A new device, used in servodrives, is the microsyn.

Microsyn - high-frequency selsyn, capable of being both sensor and setting mechanism, where the construction of microsyns for both cases of use is invariable. However, the microsyn-sensor can operate only on alternating current, and the microsyn-setting mechanism - on alternating and direct current.

The microsyn-sensors have a large advantage over potentiometric pickups, which consists of the fact that there are no sliding contacts in them. Besides this, the sensitivity threshold of wire potentiometer depends upon the wire diameter, and for the microsyn it is equal in practice to zero ( $1/600^\circ$ ), which with the rotor diameter about 18 mm corresponds to linear displacement of the rotor pole relative to the stator pole by  $0.26 \mu\text{m}$ . Consequently, when the measured angle is small, the microsyn has a considerable advantage over the potentiometer, despite the fact that the weight of the rotor highly exceeds the weight of the potentiometer brush.

For floating integrating gyroscopes, inside which are installed microsyns-sensors and controllers, this fact is not important.

Integrators convert the entering input signal into a signal of another form, described by an integral (most frequently with respect to time). For example, if electrical voltages  $U_{\text{in}}$  enters the integrator input, then at the output voltage is removed from the terminals

$$U_{\text{out}} = \int U_{\text{in}} dt.$$

For navigational inertial systems, where it is necessary to integrate the acceleration signals in a very large range (from thousandths to tenths), not only high accuracy is necessary, but also efficiency over a wide range of measurement of the input values. This problem is solved by the application of multistage integrators.

Adders are devices, algebraically summing up the information from two or several sources. Any inertial system should sum up several signals. For example, the signal from the programmed unit and the feedback signal are algebraically added to the error measurement signal of coordinates or to the signal of the first integrator.

The adders consist either of electric circuits, which include potentiometers, inductances and capacitances, or of several cascades of electron tubes. Most frequently there are used adders constructed on the basis of potentiometers, voltage dividers, control windings of the magnetic amplifier and bridge circuits.

Trigonometric devices. In the inertial systems used in navigation there is frequently performed multiplication of a measured value, for example speed (in the form of stress), by the trigonometric function of some angle, let us suppose, track.

To obtain the trigonometric functions of angle sine and cosine there are used sine-cosine potentiometers, and on alternating current - rotating transformers.

More complex trigonometric dependences are obtained with the aid of functional potentiometers.

Multiplying devices serve for the multiplication and division of two or several values. They are created on

potentiometers using bridge circuits and a magnitoelectric logometer.

The bridge circuits make it possible to multiply and divide values with considerably greater accuracy than potentiometric, since the result of measurement does not depend upon the load resistance.

Thus, because of the stabilized platform the inertial systems continuously and automatically, besides their basic function, incidentally determine the course, roll and pitch angles, i.e., the angles which characterize the aircraft position relative to the meridional planes and horizon.

The knowledge of these values with known speed of flight, distance and required direction to the point of destination (KPM, PPM) is necessary for automatic control of the aircraft with the aid of the autopilot and automation of the power-plant control.

#### COURSE AND GLIDE-PATH SYSTEMS

Ground equipment of the ILS system consists of the course and glide-path beacon and three radio marker beacons (at present the inner marker is not installed at all airports). At some airports for construction of the landing approach maneuver on the outer marker point a homer is installed.

When performing international flights two versions of the placement of ground equipment can be encountered.

The first version (Fig. 88): the radio-range beacon is located on the continuation of the RW axis and the axial line of the course zone coincides with the RW axis, i.e., its occurrence corresponds to the landing angle (landing course).

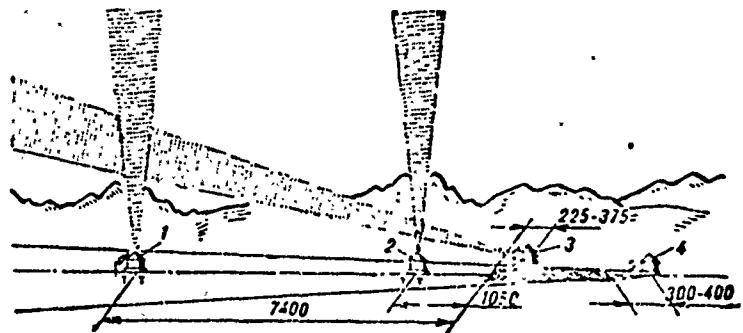


Fig. 88. The first version of placement of the ground equipment: 1 - outer marker; 2 - middle marker; 3 - glide-path beacon; 4 - runaway localizer.

The second version (Fig. 89): the radio-range beacon is located not on the RW axis, but aside it - to the right or left of it so that the axial line of the course zone passes through the middle marker point at a  $2.5\text{--}8^\circ$  angle to the landing line.

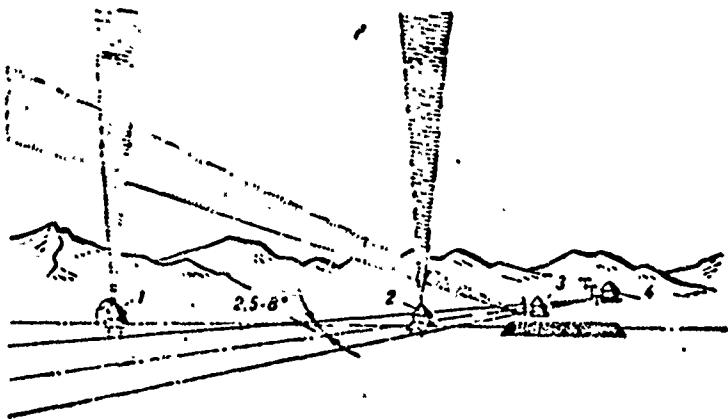


Fig. 89. The second version: 1 - outer marker; 2 - middle marker; 3 - glide-path beacon; 4 - runaway localizer.

The course beacons of the ILS system operate in the circular version. Recently beacons of the sector version have been installed: the angular width of the sector is  $70^\circ$  on both sides of the landing line. The basic characteristics of the course and glide-path zones of the ILS are given in the section of

ground equipment of SP-50, since they coincide with the appropriate characteristics of SP-50 with new adjustment.

The marker beacons of the ILS system operate on the same frequency (75 MHz) as in the SP-50 system and emit the following code signals: inner marker - six dots per second; middle marker - alternately two dashes and six dots per second; distant marker (in the ICAO materials - outer marker) - two dashes per second.

Ground equipment of the SP-50 system is placed at the airports of civil aviation according to a single standard scheme (Fig. 90).

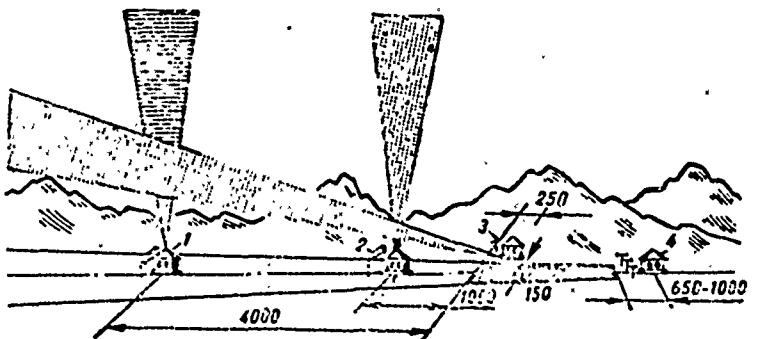


Fig. 90. Ground equipment of SP-50 system:  
1 - outer homing station; 2 - inner homing station; 3 - glide-path beacon; 4 - runaway localizer.

As a result of performed adjustment of the equipment of the SP-50 system in accordance with ICAO standards accepted for the ILS system, the course and glide-path beacons have the following technical data.

The runaway localizer zone. The center line of the course zone coincides with the RW axis (Fig. 91). The linear width of the zone at a distance of 1350 m from the touchdown point is equal to 150 m (from 120 to 195 m), which corresponds to the angular

deviation from the longitudinal axis of the RW not less than  $2^{\circ}$  and not more than  $3^{\circ}$ .

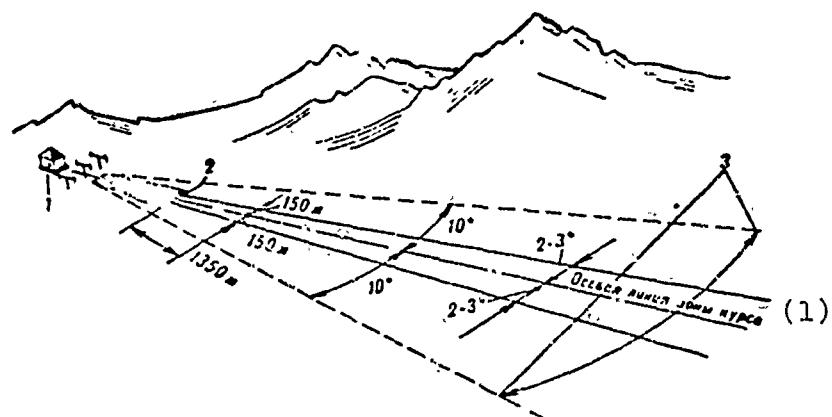


Fig. 91. The runaway localizer zone: 1 - runaway localizer; 2 - touchdown point; 3 - the point at which the range of the radio beacon (at flight altitude 1000 m) should be not less than 70 km.

KEY: (1) Center line of course zone.

The range of the beacon provides the reception of signals at a distance of over 70 km from the beginning of the RW at flight altitude 1000 m in a sector  $10^{\circ}$  wide on each side of the RW axis (see Fig. 91). For the radio range beacon of the ILS the range is stipulated 45 km at flight altitude 600 m.

The glide-path beacon zone. The optimum glide-path angle is equal to  $2^{\circ}40'$ . When obstructions are present in the approach sector the glide-path angle is increased to  $3^{\circ}20'$  and in exceptional cases can reach  $4-5^{\circ}$ . With optimum glide-path angle  $2^{\circ}40'$  the aircraft during descent flies over the outer and inner markers (with their standard arrangement) at altitudes of 200 and 60 m respectively.

The angular width of the glide-path zone with its optimum angle of slope can be within  $0.5-1^{\circ}4'$ , whereupon with increase in the slope angle the rate of descent grows, and the width of

the zone is increased for facilitating aircraft handling.

The range of the glide-path beacon provides the reception of signals at a distance not less than 18 km from it in sectors  $8^\circ$  to the right and left of the landing line. These sectors, in which the reception of signals is provided, are limited in height by the angle above the horizon, equal to 0.3 of the descent glide-path angle, and by the angle above the glide path, equal to 0.8 of the descent glide-path angle (Fig. 92).

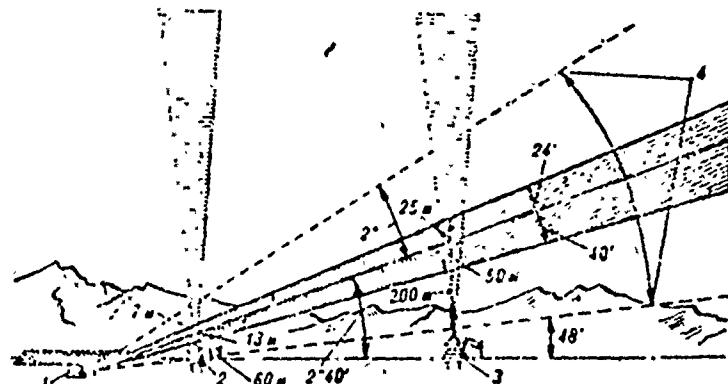


Fig. 92. The glide-path beacon zone: 1 - glide-path beacon; 2 - inner homing station; 3 - outer homing station; 4 - the sector in which the range with deviation from the landing line up to  $8^\circ$  should be not less than 18 km. With the position of the aircraft on the upper or lower boundary of the zone the PKP-48 pointer is deflected the whole scale.

Ground equipment of the SP-50M system is intended for its use during controlled and automatic landing approaches according to ICAO norms of the 1st category of complexity.

The stability of occurrence of the course center line is ensured by more stringent requirements imposed on the equipment.

The angular width of the course zone is determined by formula

$$S_K = \frac{210.57.3}{L_K},$$

where  $L_H$  - the total distance from the radio range beacon to the near end of the RW and the length of the RW; 210 m - the linear width of "corridors" on the side of the landing approach.

In cases when the RW length considerably exceeds optimum, the width of the course zone is established not less than  $1^{\circ}75'$  (half-zone).

All the remaining parameters of the course and glide-path beacons are controlled strictly in accordance with the technical standards of the ICAO.

#### The System of Command Landing Approach Control

At present on civil aviation aircraft with GTD there are installed command landing approach control system ("homing," "path"). These systems are the semi-automatic aircraft control system during landing approach.

The command instrument in such systems is the PSP-48 or KPP-M null indicator.

By semiautomatic control we mean handling the aircraft by the commanding instrument, the pointers of which during the landing approach from the moment of the beginning of the fourth turn and on the landing leg must be held on zero. Unlike the ordinary approach by the SP-50 the null indicator in this case does not inform the pilot about the position relative to the equisignal zones of course and glide-path beacons, but indicates to him which roll and pitch angles must be maintained for precise approach to the equisignal zones and following in them.

The system of command control simplifies piloting by means of the transformation of navigation and pilotage information about

the aircraft position in space and its forming into the control signal, which is identified on command instruments. The deflection of the command pointer is a function of several parameters, which in the ordinary landing approach the pilot considers on separate instruments: PSP-48 of SP-50 system, gyro-horizon, compass and rate-of-climb indicator. Therefore the command pointers are located in the center of the scale not only when the aircraft strictly follows the equisignal zones of course and glide path, but also when correct approach to the equisignal zones is accomplished.

On the aircraft, which are already in operation, there are installed simplified systems of command control, which operate on the basis of existing airborne and ground equipment: course radio receiver KRP-F, glide-path radio receiver GRP-2, navigation indicator NI-50BM or course setting mechanism ZK-2B, master vertical gyroscope TsGB or gyroscope pickup (AGD, PPS). Furthermore, the set includes: calculator, coupler with autopilot when connection with the autopilot is present on the aircraft.

The landing approach maneuver on the aircraft, equipped with command control system (Fig. 93), is executed in this way:

1. Having obtained permission for entry into the airport zone, equipped with SP-50 or ILS system, the crew, acting in accordance with the scheme approved for the given airport, guides the aircraft to the point of the beginning of the fourth turn; with this the crew is obliged:

a) to set the map angle, equal to the landing MPU for the given direction of landing, on the NI-50BM autonavigator;

b) to set the wind velocity, equal to zero on the NI-50BM wind setting mechanism;

- c) before turning on the power supply on the M-50 panel to check that the course and glide-path pointers of the null indicator are located in the center of the scale, otherwise set them with respect to the center by a mechanical corrector;
- d) to place switch "SP-50-ILS" in the position which corresponds to the system by which the approach is performed;
- e) to set on the SP-50 control panel the appropriate operating channels of course and glide-path beacons;
- f) to turn on the power supply on the M-50 panel;
- g) to turn on the power supply on the control panel of the command system;
- h) to check the operable state of the KRP and GRP by deflection of the pointers of the null indicator and by the coverage of flags on their scales (flags are covered after warming up of the receiver tubes and when signals of ground beacons exist);
  - i) during landing approach on the section between the third and fourth turn with closed flags to check the electrical zero balance of course bars, by turning the knob of the balance on the M-50 panel in some direction until the arrival of the pointer in the center of the scale. Refine the check after approach of the aircraft to a straight line.
  - 2) the moment of the beginning of the fourth turn can be determined;
    - a) with the aid of ARK by the KUR of the outer marker beacon (DPRM);

- b) by the azimuth and range of the "Svod" azimuth and range system;
- c) by the instruction of the controller, who observes the aircraft with the aid of ground radar;
- d) by airborne radar;
- e) by the scaling of the course bar of the command instrument.

3. At the moment of the beginning of the fourth turn toward the deflection of the course bar of the command instrument create a bank at which it will be set on the scale zero. During the turn the pilot should hold the pointer of the null indicator in the center of the scale, by decreasing or increasing the bank. The bank is always created in the direction of deflection of the pointer.

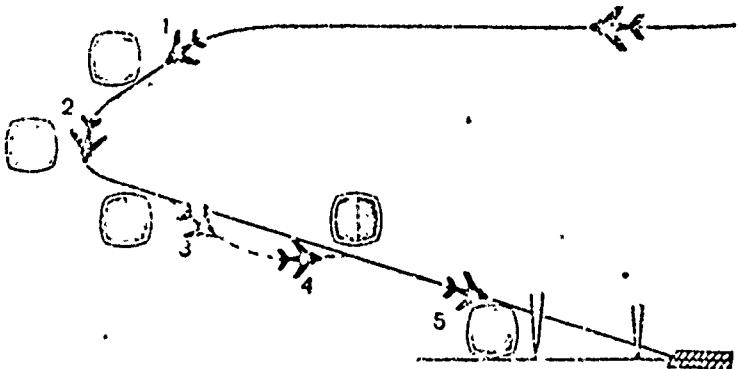


Fig. 93. Landing approach with the aid of control instrument: 1 - between the third and fourth turn both bars are off scale. The beginning of the fourth turn is determined by ARK, "Svod" or by instruction from the ground; 2 - on the fourth turn with bank course correct in amount and direction the bar is located in the center of the scale; 3 - with drift for some reason from the LZP (on a turn or on a straight line) the course pointer will indicate the direction and magnitude of the bank necessary for approach to LZP; 4 - as soon as the bank necessary for approach is created the pointer arrives at the center of the scale. Its further maintaining in this position is provided for by approach to LZP; 5 - when tracking strictly the LZP (in the equisignal zone of course and glide-path beacons) both bars are intersected in the center of the instrument.

In the case of early beginning of the fourth turn for holding the course pointer in the zero position it will be initially required to create the 17-20° bank, which subsequently must be decreased sometimes up to full recovery of the aircraft from the bank. However, with approach to alignment of the RW the course pointer of the command instrument will show the necessity for the creation of the bank required for smooth entry into the landing line.

With late beginning of the fourth turn there occurs change of course to an angle greater than 90°, and the sign of the bank is changed. With this the entire maneuver, including calculation of the drift angle, is treated by the system automatically.

With execution of the fourth turn it is necessary to constantly see that the course flags are closed on all null indicators.

4. After the execution of the fourth turn and entry into the equisignal course zone it is necessary to continue flight without descent, holding by banks the controller pointer of the command instrument in the center of the scale. In this case it is necessary to follow the pointer of the glide path, which after accomplishing the fourth turn will be deflected upward. The flags of the glide path should be closed.

As soon as the pointer of the command instrument approaches the small white circle, immediately begin descent, holding the control pointer of the glide path in the center small black circle.

5. By the altitude of flight over the outer marker beacon determine the possibility of continuation of the glide-slope descent: if over the outer marker beacon with the location of the glide-path pointer within the small white circle the flight

altitude will be equal to or exceed that established for the given airport, then it is possible to further continue glide-slope descent; if with correct maintaining of the glide path the aircraft reached the established flight altitude above the outer marker beacon and did not follow the signals of its actual flight, then immediately discontinue the glide-slope descent and in the future after passing the outer marker beacon perform descent according to the rules established for the system of OSP.

6. After passing the outer marker beacon maintain the command pointers of the command null indicator in the zero position, without allowing in this case descent outside ground visibility lower than the weather minimum established for the given airport.

With detection of the ground (landing lights) it is necessary to change to visual flight and execute the landing.

Errors in setting the course on the NI-50BM automatic device, exceeding the sum with the drift angle  $15^\circ$ , do not at all make it possible to execute landing approach using the command control system. To avoid this before the beginning of the fourth turn the navigator should again check the correctness of the setting of the "grivation" on the NI-50BM autonavigator and the correctness of operation of the course system. With readings of the magnetic course considerably larger than the actual course on the landing leg, the aircraft will be deflected to the right of the axis of the equisignal zone of the runway localizer, while with understated readings - to the left. To provide good accuracy of operation of the system on the final approach leg at large drift angles the navigator should ensure the operation of the course system with high accuracy; error should not exceed  $\pm 2^\circ$ .

Furthermore, the accuracy of bringing the aircraft to the RW axis and following along it also depends upon the accuracy

of occurrence of the zone of the runaway localizer and zero adjustment of the course pointer by turning the knob on the SP-50 panel.

#### KURS-MP-1 AIRBORNE EQUIPMENT

The KURS-MP-1 equipment makes it possible to use the foreign navigation and landing systems VOR and ILS along with the domestic "Svod" and SP-50, and also to accomplish air navigation with the aid of ARK.

For accomplishing these tasks on board there is installed the following equipment:<sup>1</sup>

- NKP-4 - navigational course instrument;
- RMI - radiomagnetic indicator;
- panel (selector) for the selection of radio systems;
- control unit (panel of adjustment of subassembly);
- azimuth selector.

The NKP-4 navigational course instrument is installed on control panels of the pilot and copilot and is intended for handling the aircraft in navigation and landing conditions. Piloting is accomplished by course and glide-path pointers (bars) just as in any null indicator. On the inner movable scale of the NKP-4 with scale value  $2^\circ$  opposite the fixed triangular index located at the top of the instrument there is read the aircraft course. The outer fixed scale, which has  $10^\circ$  divisions, serves for reading the radio station angles of approach. Since the NKP-4 is connected to the navigator's indicator (USh), it repeats all its readings.

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<sup>1</sup>The given description has been made as applied to the Il-18 aircraft. However the assembly and the procedure for the use of equipment are similar for all the aircraft on which it has been installed. Only the arrangement of separate units and instruments in the compartments is changed.

The instrument has two pointers: yellow (narrow) and white (wide). The yellow narrow pointer is intended for reading the KUR only with the aid of the one first set of ARK. On some aircraft this pointer can be inactive. The white wide pointer of the course selector is driven by a rack-and-pinion gear, located in the lower right corner of the NKP-4. The course should be set only when piloting by the command pointers (in the command mode).

The center section of the instrument is occupied by a null indicator with white course and yellow glide-path bars and by their flags of the appropriate colors.

Air navigation using the VOR system is accomplished using only the white (course) bar: if the specified track coincides with the azimuth line on the VOR beacon, the crew should hold the course pointer within the small white circle.

During landing approach both pointers are used: course and glide-path.

Radiomagnetic indicator RMI is installed on the instrument panels of both pilots and serves for taking readings of the magnetic course, bearings (azimuths) and radio station and beacon angles of approach (see Fig. 70).

The RMI instrument also has two scales: inner - movable with scale value  $2^\circ$  and outer - fixed, on which every  $45^\circ$  there are placed triangular indices or (on the latest issues) points at four headings:  $240$ ,  $290$ ,  $70$  and  $120^\circ$ .

Since the RMI is connected directly to the gyrounits of the course system (KS), by the inner slide scale opposite the fixed triangular index there is always read the MK of the aircraft regardless of the position of the switch on the control panel of the navigator's course system.

The narrow and wide pointers of the instrument are intended for reading the headings and azimuths (bearings) of radio stations and VOR beacons. In this case:

the narrow pointer shows the bearing and heading only of the first (main) ARK set, tuned to the homing station, or the first subassembly of KURS-MP-1, tuned to the VOR radio beacon;

the wide pointer shows the bearing and heading of only the second (spare) ARK set or the second subassembly of the KURS-MP-1 device, tuned to the VOR beacon.

Switching the instrument to operation of the first or second ARK set or KURS-MP-1 subassembly by radio station or ground VOR beacon is accomplished by two flags at the bottom of the instrument: left - with narrow handle and right - with wide. The positions of the handles (flags) are fixed by labels in the viewing windows located under them, respectively: in the left - "ARK1" and "VOR1," in the right - "ARK2" and "VOR2."

Depending on the position of the left narrow switch the narrow pointer of the instrument will show either the KUR of the radio station to which the ARK1 is tuned, or the azimuth of the VOR beacon, working with the first KURS-MP-1 subassembly. Depending on the position of the right wide switch the wide pointer will show the KUR of the radio station to which the ARK2 is tuned or the azimuth of the VOR beacon, working with the second subassembly of the KURS-MP-1 equipment.

The radio-system selection panel is designed for the selection of the radio systems, by which air navigation and piloting will be accomplished in navigation and landing conditions (RSBH, VOR, ILS and SP-50).

On Il-18 aircraft the panel is located over the middle instrument panel in the cockpit and has three switches. In the upper left corner of the instrument panel there is a switch, which determines the system by which the landing approach is performed. It has two positions: "ILS" and "SP-50." In the upper right corner of the instrument panel there is installed the marker switch, which in route flight must be placed in the "landing" position.

In the bottom of the panel is a switch with five fixed positions:

- 1) "RSBN" - to the pilot and copilot NKP-4 instruments are fed signals from the "Svod" system;
- 2) RSBN/"SP-50" - to the aircraft commander's NKP-4 are fed signals only from the "Svod" equipment, and to the copilot's NKP-4 only from the SP-50 system of the first KURS-MP-1 subassembly. With malfunction of the first subassembly of KURS-MP-1 equipment the copilot's NKP-4 instrument is automatically switched to the second subassembly (for this it is necessary on both subassemblies to set the frequency of the SP-50 of the landing airfield);
- 3) the "1" position - on the aircraft commander's and copilot's NKP-4 only the first subassembly operates. In the case of its failure the second subassembly is automatically connected. This operating condition of KURS-MP-1 equipment is the main one during landing approach using ILS and SP-50 systems;
- 4) the "combined" position - the signals proceed to the aircraft commander's NKP-4 only from the first subassembly, and to the copilot's NKP-4 - only from the second subassembly. In this position redundancy is not provided.

5) position "2" - signals proceed to both NKP-4 only from the second subassembly. In this position the second subassembly is not reserved automatically by the first, since it has been provided in case of breakdown of the first subassembly and the automation of switchovers.

A control unit is located in each subassembly and is designed for tuning this subassembly to the operating frequencies of VOR, SP-50 and ILS ground beacons.

Beacon frequencies in the 108-118 MHz range are established with the aid of a drum and flag. When setting odd frequencies in the 108.1-111.9 MHz range the ILS mode is automatically turned on, and when setting the 112.0-117.9 MHz range and even frequencies in the 108.2-111.8 MHz range - VOR mode.

The azimuth selector is in both KURS-MP-1 subassemblies and serves to facilitate flight in a certain direction (azimuth), strictly oriented in space relative to the ground beacon of the VOR system. This is accomplished by setting the value of this azimuth on the selector.

Its second purpose is determining the precise value of the azimuth of the VOR beacon during the solution of navigational problems.

At the top of the selector are located two light signal panels: on the left - "To," and on the right - "From." On the lighting of one of them it is possible to judge the heading to the beacon or from it. In the center of the selector is a window, behind which is located a drum, numbered from 1 to 360° with scale value 1°. In the lower right corner of the selector is located a handle, with the aid of which there is set the given value of the azimuth, along which flight is accomplished by the null

indicator, while in the left lower corner - a flag for change of azimuth to 180° with simultaneous phase transfer.

Automatic phase transfer occurs during flight past the VOR beacon. This provides the correct readings of the pointer of the NKP-4 null indicator with further holding of the aircraft on the LZP (pointer on the right - LZP to the right, pointer on the left - LZP on the left). Consequently, at the moment of flight past the beacon it suffices with the aid of the right lower handle to only refine the value of the new azimuth, by which further flight of the aircraft will be performed.

The manual transfer of the flag and change of the value of the azimuth 180° are performed only when the aircraft, without flying to the beacon, made a turn close to 180° for further flight in the opposite direction. In all other cases the flag should be dropped down.

#### The Operational Capabilities of KURS-MP-1 Equipment

1. Simultaneous operation by two different VOR beacons -- basic version during flight along routes equipped with VOR systems. The indication of azimuths and KUR of both beacons is accomplished on RMI instruments, and indications of azimuths on the outer scale of the navigator's indicator - only with setting of the switches (narrow and wide flags) of RMI in the "VOR1" and "VOR2."
2. Simultaneous operation of one subassembly in the VOR mode, and the second - in the ILS mode is used in accomplishing the prelanding maneuver, if the VOR beacon is located near the landing airfield. In this case it is more expedient to work in the "Combined" mode. The first subassembly is tuned to the ILS beacon, the second - to the VOR beacon. At the moment of entry into the zone of the ILS course localizer the switch on the radio-system

selection panel is placed in the position "1" and for reservation of the landing channel the second subassembly is changed over to the ILS beacon by setting the frequency at which it operates on the control units.

3. Simultaneous operation of two subassemblies in the mode of SP-50 or ILS localizer beacons - main version when accomplishing the landing approach by the course and glide-path beacons.

Both subassemblies are tuned to the frequency of the landing system of the given airfield.

For reservation of the landing channel the switch on the radio-system selection panel is placed in position "1." To both NKP-4 navigational course instruments signals are fed from the first subassembly of KURS-MP-1 equipment.

#### The Problems Solved by KURS-MP-1 Equipment in the Navigation Mode

1. Determining the magnetic azimuth (bearing) from the aircraft position to VOR ground beacon.

2. Flight along the equisignal zone of the given magnetic azimuth of the ground beacon (with its agreement with the LZP) with the use of the null indicator.

3. Determining the aircraft position from the magnetic azimuth of two VOR beacons and determining the navigational elements during steady-state aircraft flight.

4. If the aircraft is equipped with "Svod" equipment, then the solution of all problems provided by this system is possible. In this case, with the establishment of mode "RSBN" "SP-50,"

on the radio-system selection panel, the aircraft commander's NKP-4 will operate similar to the KPP-M of the "Svod" system.

Turning on the KURS-MP-1 equipment and determining its readiness for operation:

1. Turn on the power supply of the equipment with the five AZS on the navigator's TsRSh: "KURS-MP signal," "KURS-MP-1," and "KURS-MP-II," "RMI-I," and "RMI-II." It is necessary to remember that the equipment should be turned on 5-10 min before the beginning of operation for warming up its elements, stabilization of operation and final adjustment of servomechanisms in the initial position.

2. Place the function selector on the radio-system selection panel in position of the system selected for use, and also place the "ILL-SP-50" switches and "Route-Landing" marker in the appropriate positions.

3. On the control units set the frequency of the selected VOR, N-50 or ILS beacon.

4. Set the azimuth on the selector.

5. Place the switches on the aircraft commander and copilot RMI in the appropriate position: "ARK1," "VOR1," "ARK2," "VOR2."

6. For the navigator set the switch "ARK1," "VOR1" and "ARK2," "VOR2" in the necessary position.

The readiness of the subassemblies of the equipment for operation in the navigation mode is determined by:

the course ("K") signal lamps going out on the radio-system selection panel (left - the first subassembly, right - the second);

coverage of the white course blinkers on NKP-4 instruments.

The readiness of the subassemblies of the equipment for operation in the "Landing" mode is determined by:

the course ("K") and glide-path ("G") signal lamps going out on the radio-system selection panel;

by coverage of the white course and yellow glide-path indicators on NKP-4 instruments.

In the "Navigation" and "Landing" modes on the signal panel located on the pilot's and copilot's control panels the signaling of the selected operating mode should light up: VOR, SP-50 or ILS.

#### The Use of KURS-MP-1 System

During flights by VOR beacons:

1. Check the connection of the power supply of the equipment.
2. Set the frequency of the selected VOR beacon on the control unit. In the commander's and copilot's light signal panel the label VOR will appear.
3. Listen to the call sign of the VOR beacon, having placed the switch of the subscriber's set of the SPU in the "RK1" position for the first subassembly and in the "RK2" position for the second, and set switches "ARK1, VOR1" and "ARK2, VOR2" in the "VOR1" and VOR2" positions. In this case on the KUR scale of the USh it is possible to read the azimuths of VOR beacons, indicated by the ARK pointers.

4. On the radio-system selection panel set the operating mode of the equipment ("1," "Combined," "2").

5. Place the RMI flags in the "VOR1" and "VOR2" positions.

6. For flight to the VOR beacon or from it on the selector set the magnetic azimuth taken from the chart. In this case the label "To" or "From" respectively should light up.

In all cases, regardless of whether flight to the beacon or from it is accomplished, the magnetic azimuth will be close to the magnetic course and be different from it only by the magnitude of convergence of meridians, by the difference of magnetic declinations of the aircraft position and the installation point of the beacon, drift angle and error in the course system.

After setting the given azimuth by the position of the course bar of the NKP-4 the aircraft position is determined relative to the LZP, approach to it is performed and it is followed with the aid of the null indicator in the usual order. With this the pointers of the RMI during the entire flight show the azimuth of the VOR beacon, to which the subassemblies of KURS-MP-1 equipment have been tuned.

Approach to the VOR beacon is carried in the following manner: there is taken the MK, equal to the azimuth taken from the RMI, it is set on the azimuth selector and the aircraft is piloted by the course bar of the NKP-4.

When taking the azimuth to the VOR beacon by the outer fixed scale of the USh opposite the sharp ends of indicator pointers it is necessary to place the switches "ARK1-VOR1" and "ARK2-VOR2" in the "VOR1" and VOR2" positions.

Landing by the ILS system:

1. Before switching on the power supply of the equipment check that the NKP-4 bars are in the cross-hairs of the scales, if not, then set them in this position with the mechanical correctors. One should remember that with power supply of equipment connected the indicated correction is forbidden, since this will lead to distortion of the NKP-4 readings.
2. Connect the power supply of KURS-MP-1 equipment.
3. On the control units of both subassemblies set the operating frequency of the ILS beacon.
4. On the control units of both subassemblies the operating frequency of the ILS beacon.
5. Place the switches on the RMI in the "ARK" and "ARK2" or "VOR1" and "VOR2" positions depending on which radio aids will be used in the prelanding maneuver.

The readiness of the subassemblies of KURS-MP-1 equipment for operation with ILS beacons is determined by:

- a) the course ("K") and glide-path ("G") signal lamps going out on the radio-system selection panel;
- b) coverage of course (white) and glide-path (yellow) blinkers on NKP-4 instruments.

Landing by the SP-50 system:

1. Correction of the null indicator is performed exactly as when landing using the ILS system. One should remember that here correction is also forbidden with the power supply of

equipment connected, in order to avoid incorrect readings of NKP-4 instruments.

2. Connect the power supply of the equipment.

3. On the radio-system selection panel place the switches in the "SP-50" positions, "Landing" and "1" positions.

4. On the control units of both subassemblies set the operating frequency of the SP-50 beacon of the landing airfield.

5. On the RMI place the switches in the "ARK1" and "ARK2" positions.

6. Check the electrical null of equipment.

The aircraft commander should check the placement of the switch levers on the radio-system selection panel in the "SP-50" and "1" position and press the "Balance-I" knob on the balance board. If in this case the course bar of the NKP-4 is not placed in the center of the null-indicator scale, then by rotating the pressed "Balance-II" knob to the right and left set the bar in the center of the cross-hair, then release the knob.

With the "Balance-II" knob do the same operations for the second subassembly of equipment, having preliminarily placed the switch on the radio-system selection panel in the "2" position. It is necessary to remember that the electrical null can be checked only in the zone of coverage of the SP-50 radio range beacon with deflected course bars, signal lamps out and NKP-4 blinkers closed.

The readiness of the subassemblies of KURS-MP-1 equipment for operation with SP-50 beacons is determined by:

a) course ("K") and glide-path ("G") signal lamps out on the radio-system selection panel;

b) coverage of course and glide-path blinkers on NKP-4 instruments.

During piloting with the NKP-4 on the last straight line using both the SP-50 and ILS systems the usual procedure for landing approach by the course and glide-path systems is used.

#### AIRBORNE SYSTEM BSU-ZP

The BSU-ZP airborne control system consists of the following main parts:

1. Flight system "Put'-4MPA," providing:

a) aircraft control by the command pointers of the PP-1PM flight instruments during landing approach from the beginning of the 4th turn;

b) sending of command signals to the autopilot AP-6YeM-ZP through BS-3 coupler;

c) indication of the basic aircraft location parameters.

2. The AP-6YeM-ZP autopilot, which accomplishes:

a) stabilization of center of gravity of the aircraft relative to a given trajectory, using the signals of the altitude corrector and "Put'-4MPA" system;

b) stabilization of the angular positions of the aircraft around the center of gravity under all operating conditions, starting with altitude 200 m, including during acceleration and braking.

Table 3. The situations of failure of KU-2T and KU-4 during a star landing  
accr. a/cn.

Failure of lateral channel of AP	Failure of "12V" channel of AP	Failure of the "12V" supply of AF C. direct and alternating current	Misalignment of "KGV" with respect to bank by 10°	Misalignment of "KGV" with respect to pitch by 5°	Failure of automatic twin control	Misalignment of second pointers of longitudinal channel of "Put-MPA" by 6 mm	Misalignment of second pointer of lateral change of "Put-MPA" by 6 mm	Failure of both sets of KURS-MP-1 (or ground beacons) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path
Audible signal. Signal "Put-lateral" lights up. On the panel "Put-lateral" the button "Put" is switched off, button "Put" is pressed.	Audible signal. Signal "Put-lateral" lights up. On the panel "Put-lateral" the button "Put" is switched off, button "Put" is pressed.	Audible signal. Signal "Put-lateral" lights up. On the panel "Put-lateral" the button "Put" is switched off, button "Put" is pressed.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.	Radio signal. Signal "Put-lateral" and "AP longitudinal" lights up. On the panel "Put-lateral" the button "Put" is switched off, button-lamps "Course" and "Glide-path" go out.
Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path
Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path
Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to course	Failure of both sets of KURS-MP-1 (or ground equipment) with respect to glide path

Table 27. Signaling of failures of BSU-ZP and KURS-MP-1 during ground-controlled landing approach.

Malfunction	Signaling
Misalignment of TSGV with respect to bank by 10°	Signal panel "TSGV" and "Path lateral" lights up
Misalignment of TSGV with respect to pitch by 10°	Signal panel "TSGV" and "Path longitudinal" lights up
Misalignment of command pointers of the lateral channel of "Put' -4MPA" system by 6 mm	Signal panel "Path lateral" lights up
Misalignment of command pointers of limiting channel of "Put' -4MPA" system by 6 mm	Signal panel "Path longitudinal" lights up
Failure of both sets of KURS-MP-1 (or ground beacons) with respect to course	Signal panel "KRP" lights up. On the NKP-4 the course blinker is open
	On the KURS-MP-1 panel signaling K <sub>1</sub> and G <sub>1</sub> lights up
Failure of both sets of KURS-MP-1 (or ground beacons) with respect to glide path	Signal panel "GRP" lights up. On the NKP-4 the glide-path blinker is open
	On the KURS-MP-1 panel signaling G <sub>1</sub> and G <sub>2</sub> lights up

Table 28. Signaling of failures of BBSU-ZP in the aircraft stabilization control modes through the autopilot.

Malfunction	Signaling
Failures of longitudinal channel of AP	Audio signal. Signal panel "AP longitudinal" lights up. On the PU of AP the longitudinal stabilization blinker is switched off, button-lamp "KV" goes out
Failure of lateral channel of AP	Audio signal. Signal panel "AP lateral" lights up. On the PU of AP the transverse stabilization blinker is switched off
Failure of power supply of AP on direct or alternating current	Audio signal. Signal panel "AP lateral" and "AP longitudinal" lights up. On the PU of AP the transverse and longitudinal signaling blinkers are switched off, button-lamp "KV" goes out
Misalignment of TsgV with respect to bank by $10^\circ$	Audio signal. Signal panel "AP lateral" and "TsgV" lights up. On the PU of AP the transverse stabilization blinker is switched off
Misalignment of TsgV with respect to pitching by $5^\circ$	Audio signal. Signal panel "AP longitudinal" and "TsgV" lights up. On the PU of AP the longitudinal stabilization blinker is switched off, button-lamp "KV" goes out
Failure of automatic trim control	On the signal panel "Automatic trim control" lamp UAT-3 lights up

Note: There are no fundamental differences between the operation of the signaling of failures on the Tu-134 and Il-18 aircraft. The only difference is the site of installation of signal panel and push button-lamps, depending on the layout of the flight decks. Furthermore, in BSU-ZP of new series, unlike the initial some signal panels have been added. For example on the Il-18 with BSU-ZP of series 01 the signal panels "AT-2," "KRP," "GRP," "KURS," "GLISS," "KV," and "TsgV" have been installed.

During stick control "Turn" or "Descent-Climb" the pilot can maneuver in horizontal and vertical planes, namely: go into a turn with bank up to 22° or change the pitch up to 10°.

3. Automatic trim control AT-2, which provides indication and automatic removal of forces by the elevator in the control system, which appear with change in the flight mode and the center of gravity position of the aircraft. The automatic trim control is turned on simultaneously with actuation of the longitudinal channel of the autopilot and it operates throughout the flight under the autopilot. When accomplishing automatic landing approach it is switched off simultaneously with cutoff of the autopilot by the rapid cutoff knob.

The BSU-ZP system solves the following problems:

automatic and command aircraft control during landing approach by the signals of radio beacons of the SP-50M system or ILS system up to altitude 60 m (from the beginning of the fourth turn on course; and by the longitudinal channel - from the moment of entry into the glide path);

the automatic stabilization of the angular position of the aircraft in space and the barometric flight altitude, and also the aircraft control through the autopilot in all ranges of operational altitudes, beginning with an altitude of 200 m.

Furthermore, the BSU-ZP system makes it possible to accomplish combined aircraft control during the landing approach:

- a) on course - automatically, on the glide path - on a directional pointer;
- b) on course - on a directional pointer, on the glide path - automatically.

Also possible is a combination of automatic control on one of the channels with piloting on position strips on another channel.

#### Action of the Crew in the Case of Failures of the BSU-ZP

In the case of failures of the BSU-ZP the crew has to turn off the autopilot or to discontinue piloting by command pointers, if:

the signaling of failures of the BSU-ZP operates;

the bank of the aircraft when using the crank "Turn" is more than  $25^\circ$ ;

the deviation of the aircraft from the course and glide path zones exceeds the permissible limits when passing the outer marker beacon and the inner marker beacon;

after inscription into the equisignal sector of the course the banks exceed  $10^\circ$ ;

after inscription into the zone of the glide path the vertical rate of descent is greater than 6 m/s;

jerks or twitchings of the controls appear;

vertical overload changes by more than  $\pm 0.5$ .

In the absence of visual orientation in the mode of automatic or command landing approach, having detected the failure of the BSU-ZP, it is necessary to turn off the autopilot by the rapid disconnect button and switch to manual piloting. If the autopilot is not switched off by the rapid disconnect button it is

necessary to immediately turn off consecutively the switches "AP podg," "Transverse," and "Longitudinal."

In the case of failure of the BSU-ZP the action of the crew should be the following.

In the mode of automatic landing approach:

1. The triggering of signal panel "TsGV" with the simultaneous triggering of signal panel "AP lat." or AP long." and signal panel "Path lat." and "Path long." in the case of disconnection of the appropriate channel of the automatic machine with the delivery of sound signaling indicates the failure of one of the TsGV.

With the triggering of the signal panel "TsGV" the crew has to:

disconnect the autopilot by the rapid disconnect button;

compare the readings of the PP-1PM instruments with the AGD-1 and EUP-53, determine if the PP-1PM is operable, i.e., the TsGV is operable and change over the switch key on it;

turn off the switches "AP podg," "Transverse," and "Longitudinal," whereupon the siren and signal panel cease to operate;

in forward flight correct course system;

in the condition of manual control for working with the PP-1PM and AGD-1 complete the landing approach.

On aircraft which have the BKG-1 approach is solved in an automatic mode in the event of failure of one of the TsGV.

2. The triggering of the signal panel "AP lat." or "AP long." with the delivery of sound signaling attests to failure and disrepair of the appropriate channel of the autopilot. In this case the actions of the crew are the following:

disconnect the autopilot by the rapid disconnect button;

compare the readings of the instruments of the PP-1PM with the AGD-1 and EUP-53, being certain of their soundness;

be certain of the soundness of the KS.

Repeated connection of the autopilot is permitted only if there is confidence that the disconnection was false, as occurs during the control from the cranks "Turn" and the "Descent-Climb" or during the lowering of flaps. If there is a repeated signal response of failure on the same channel it cannot be used and it is necessary to switch to manual piloting.

3. The prolonged (more than 6 s) burning of the AT-2 warning lamp with the simultaneous presence of non-trimmed forces in the elevator channel (on indicator UAT-3) attests to the failure of the automatic trimmer. On aircraft with an improved system in this case the signal panel "Automatic trimmer" and the tube for indication of forces burn. In this case it is necessary:

to turn off the longitudinal channel of the autopilot by the switch "Long." on the control panel while holding the control wheel by hand;

to remove the forces from the elevator by the mechanical trim tab;

to complete approach in the command mode of control on the longitudinal channel (at the moment of the entry into the glide path press and release the "Glide-path" button-lamp).

4. The triggering of the signal panel "Path lat." or "Path long." indicates a breakdown of the command system. The crew should disconnect the appropriate channel of the autopilot and through this channel carry out the landing approach using the strip of position NKP-4.

The repeated connection of the autopilot is permitted if there is confidence that the signal response was false.

5. The triggering of the warning lamps "KRP" or "GRP" (in the modified system - by the signal panel "KRP," "GRP") and the dropping out of the appropriate indicators on the NKP-4 indicates the failure of both assemblies of KURS-MP-1 or the failure of ground beacons.

With this failure the appropriate channel of the autopilot is switched off and the crew performs the landing approach using the OSP and RSP systems [Translator's note: RSP - expansion unknown].

In the mode of command landing approach:

1. The triggering of the signal panel "TsGV" with the simultaneous triggering of the signal panel "Path lat." or "Path long." indicates the failure of one of the T. GV. In this case it is necessary:

to discontinue piloting on T. and pointers;

to compare the readings of the PP-1PM with the AGD-1 and

EUP-53, determine the operable TsGV, and set the TsGV switch on it;

in forward flight to correct the course system;

to set the "STU" switch in the "Off" position;

on the working PP-1PM and AGD-1 to complete the landing approach.

2. The triggering of the signal panel "Path lat." or "Path long." indicates disrepair of the command system. In this case the crew must:

discontinue piloting on command pointers;

set the "STU" switch in the "Off" position;

be convinced of the FP-1PM, having compared their readings with the readings of the AGD-1 and EUP-53;

complete the landing approach on the KGG, OSP, and RSP.

3. The triggering of the warning lamps "KRP" and "GRP" and the falling out of the appropriate drops on the NKP-4 attests to the failure of both KURS-MP-1 assemblies or the ground beacons. With this failure the crew should make the landing approach using the OSP, RSP and the working channel of the KGG.

In the mode of automatic stabilization and aircraft control through the autopilot:

1. The triggering of the signal panel "TsGV" with the simultaneous triggering also of the signal panel "AP lat." or

"AP long." and the disconnection of the corresponding channel of the autopilot with the delivery of sound signaling indicates the failure of one of the TsGV.

Having seen the triggering of the signal panel "TsGV" the crew is obliged;

to disconnect the autopilot by the rapid disconnect button;

by a comparison of the readings of the PP-1PM with the AGD-1 and EUP-53 to determine the operable TsGV and to set on it the switch "TsGV";

to turn off the switch "AP podg." having thus terminating the signaling of the siren and signal panel;

in forward flight to correct the KS;

if on the aircraft there is a BKG-1, to again connect the automatic machine. In the absence of BKG-1 repeated starting of the autopilot is forbidden.

2. The triggering of the signal panel "AF lat." or "AF long." with the delivery of sound signaling attests to disconnection and disrepair of the corresponding channel of the autopilot.

The crew should:

turn off the appropriate switch "transverse" or "long.;"

compare the readings of the PP-1PM with the AGD-1 and EUP-53 and be certain of their soundness;

be convinced of the soundness of the course system.

If the crew is confident that the signal response of failure was false, repeated connection of the autopilot is permitted, but without its use in the event of a secondary signal response.

3. Prolonged, more than 6 s, burning of AT-2 warning lamps with the simultaneous presence of untrimmed forces in the elevator channel (based on the UAT-3) indicates the failure of the automatic trimmer. If on the aircraft the system has been modified, then in the event of failure the signal panel of the "Autotrimmer" and the tube for indication of forces light up.

In the event of failure of the automatic trimmer the crew must:

turn off the longitudinal channel of the autopilot while holding the steering control manually;

remove the force from the steering control by the mechanical elevator trim tab;

turn off the AZS-AT-2;

again turn on the longitudinal channel of the autopilot;

After this acceleration and braking are carried out with the longitudinal channel of the autopilot turned off.

In 1-1.5 h switch the autopilot off and on, thus removing the forces from the elevator control and the mechanical trim tab.

#### NAVIGATION COMPUTER

The navigation computer is intended for automatic air navigation on route and in the zones of airports for departure and landing. It ensures:

the continuous automatic determining of the present-position data of aircraft in the main or particular coordinate system by the method of dead reckoning;

the conversion of calculated coordinates of the aircraft;

a) in flight in the main orthodrome - relative to the introduced coordinates of the intermediate points of the route;

b) in flight in a particular orthodrome - relative to the following section of route;

flight by the shortest distance to any point of the route.

the correction of calculated coordinates according to the radio equipment of the RSBN system (automatically) and based on radar reference points using the RPSN radar (semi-automatic);

the interpretation of radar unidentified reference point according to data from the RPSN;

the determining and display of wind velocity and wind direction;

the delivery of ZPU signals to the NPP and USh-3 indicators;

forming and delivery into the automatic device of the ready signals of the lateral deviation and course angle of the OZPU.

In calculator the digital method is used for the indication of all parameters, except the values of IZPU, OZPU, U and  $\delta$ , which are counted off on the sliding scales of master indicators. The calculator ensures the motor installation, automatic input, and indication of the following parameters:

the coordinates of the aircraft  $X_c$  and  $Y_c$  - on the calculator-indicators of units P-2-1 and P-3-1;

current calculated particular orthodromic coordinates  $Z$  and  $S$  relative to assigned course - on counters on which the lamps with the symbols "Z" and "S" are lit up;

the current orthodromic coordinates of aircraft X and Y in the main orthodromic coordinate system - on the counters with display lamps "X" and "Y";

the current particular orthodromic converted coordinates of the aircraft  $Z_{np}$  and  $S_{np}$  relative to the following assigned course line - on counters without the literal signaling of coordinates;

the coordinates of intermediate point  $X_n(Z)_n$  and  $Y_n(S)_n$  on counters with display lamps which have the appropriate designations;

coordinates  $Z_{pc}(Z_p)$ ,  $S_{pc}(S_p)$ ,  $X_{pc}(X_p)$  and  $Y_{pc}(Y_p)$ , the beacons of the RSBN or the radar reference points relative to the current assigned track or main orthodrome - on counters on which the display lamps with the appropriate images are lit up;

the given course angle OZPU1 of the current specified track on scale No. 1 and the given course angle OZPU2 of the following specified track on scale No. 2 of the master-indicator of the OZPU of unit P-12, true given course angel (IZPU) or the orthodromic track angle of the meridian (OPUM) on the scale of the IZPU controller unit P-9;

the velocity and direction of wind - on the scale of the wind controller (unit NV-2P), the distance which remains to the PPM, and number of the nearest PPM or TPM on unit P-33.

## The Preparation of Data for Programming of Flight

For the accomplishing of flight using the navigation computer the navigator has to prepare the following data:

given course angles;

the middle latitude of the sections of route;

the length of the sections of route;

the rectangular coordinates of radio correction aids;

the azimuths of orthodromes relative to the meridians of the RSBN ground beacons.

The given course angles of the sections of route are determined from the formulas:

$$\begin{aligned} ZPU_1 &= \alpha_{\text{u}} + \sigma_{\Sigma} + \delta_{\text{MP}}; \\ ZPU_2 &= ZPU_1 + \gamma_{\text{P}_1}; \\ &\vdots \\ ZPU_n &= ZPU_{n-1} + \gamma_{\text{P}_{n-1}}. \end{aligned}$$

where  $ZPU_1, ZPU_2, \dots, ZPU_n$  - the given course angles of sections of route;

$\sigma_{\Sigma}$  - the total convergency of meridians between the IPM and KPM;

$\delta_{\text{MP}}$  - the magnetic declination of the landing airfield;

$\alpha_{\text{u}}$  - the azimuth of the orthodrome relative to the meridian of the IPM;

$UP_1, UP_2, \dots, UP_{n-1}$  - the angles of turn (Fig. 94).

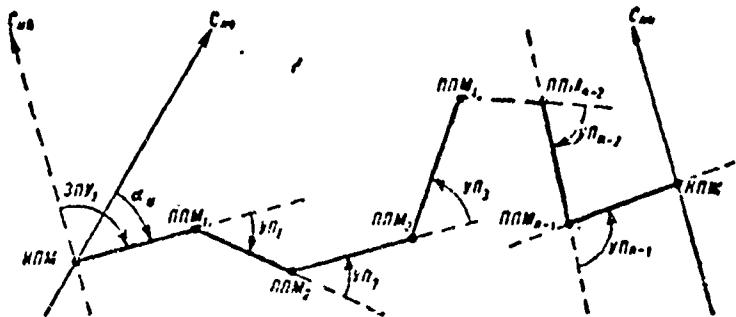


Fig. 94. The system of turn angles (UP).

Departure from the airfield zone can be accomplished by two methods. If aircraft before leaving on the IPM (the last point of the exit corridor) should pass over several sections of small length, then the mode of the main orthodrome ("GO") and shortest distance ("KR") is used. In the remaining cases the mode of particular orthodrome ("ChO") is used.

#### Departure of the Aircraft from the Airfield Zone in the Mode "GO"

1. Before taxiing out for a takeoff (after turning on the AZS):

set the "GO-ChO" switch in the position "GO";

turn on the toggle switch "Network";

on the  $X_e$  and  $Y_c$  indicators set the values  $X = 0$  and  $Y = 0$ ;

on the master-indicator of the OZPU set the value of the magnetic heading of takeoff;

on the master-indicator of the PPM coordinates set the value of PPM coordinates in the zone of the airfield;

turn on the toggle switch "KR" on the P-14 unit.

On the master-indicator of the OZPU<sub>2</sub> the ZPU on the first PPM from the center of the RW should be developed.

On the counters of present-position data "Z" and "S" Z = 0 and S should be worked out equal to the distance from the center of the RW to the PPM<sub>1</sub>. One should compare this value with that taken from a map and on the master-indicator for the coordinate of correction and IZPU the data for correction is set.

2. After taxiing to the axis of the RW carry out the initial display of the TKS-P gyro-assemblies.

Set the switch "Users" in the position "Counter."

Place switch "Calculate" in the position "Anal." (during take-off run).

3. At an altitude of 1000 m connect the calculator.

4. During approach to the PPM, at a distance of 10-20 km from it:

turn on the toggle switch "KS" on the P-14 unit;

on the indicators of PPM coordinates set the value of the next PPM coordinates.

5. After flight over the PPM the toggle switch "KS" is turned off. The aircraft will follow to the next PPM. The correction of coordinates according to the R3BN is performed when necessary.

6. After turning on the IPM (the last PPM in the zone of the airfield) switch to the calculation of coordinates in the mode "ChO," for which:

toggle switch "KR" on unit P-14 is turned off;

the switch "GO-ChO" is set in position "ChO";

on the master-indicator of the OZPU of unit P-12 set the ZPU value, and on the PPM set the distance to the IPM.

7. After flight over the IPM on the master-indicator of the PPM of units P-4 and P-5 set the value  $Z = 0$  and  $S$  equal to the length of the second section of the route.

The order of operation in the following stages is analogous.

#### The Departure of an Aircraft from the Zone of an Airfield and Flight Enroute in the Mode "ChO"

As the IPM the center of the RW of the airfield of takeoff is taken.

1. Before taxiing:

the switch "LZP-1-LZP-2" is set in the position "LZP-1";

the switch "GO-ChO" - in the position "ChO";

the toggle switch "Network" is turned on;

on the counters of the present-position data of units P-2 and P-3 set the values  $Z = 0$  and  $S$  equal to the length of the first section of route;

on the master-indicator of unit P-12 set the values of  $ZPU_1$  and  $ZPU_2$ ;

on the controllers of the PPM coordinates of units P-4 and P-5 set the values  $Z = 0$  and  $S$  equal to the length of the second section of route;

switch "LZP-1"- "LZP-2" is set in a neutral position.

2. Having taxied to the axis of the RW, set the initial display of the TKS-P gyro-assemblies and set the switch "Users" in the position "Contr."

3. During the take-off run in the center of the RW the switch "Calculate" on unit P-14 is set in the position "Anal." or "Pulsea."

4. During the climb to 1000 m follow the PPM, having hooked up the calculator.

On the master-indicator of the OZPU of unit P-12 advance the value of the ZPU of the next section of the LZP.

On the controllers of PPM coordinates of units P-4 and P-5 set the value  $Z = 0$  and  $S$  equal to the length of the next section of track.

Flight on the Shortest Distance with Calculation of Coordinates in the Mode "Ch0"

The mode "KR" (shortest distance) is used if necessary for changing the route and going to a new PPM.

For this it follows:

on the controllers of the PPM coordinates of units P-4 and P-5 set coordinates Z and S of this PPM relative to the current track.

The given course angle of new PPM should be worked out on the free master-indicator of the OZPU, and on the free counters of present-position data values  $Z = 0$  and  $S$  equal to the distance to the new PPM should be developed;

switch "LZP-1-LZP-2" is set in a neutral position.

With this the aircraft will follow the shortest distance to the new PPM.

#### Correction of Calculated Coordinates According to the RSBN

On the controllers of correction coordinates of units P-6 and P-7 set the value of the rectangular coordinates  $Z_p$  and  $S_p$  relative to the current assigned track.

On the master-indicator of the IZPU of unit P-9 set the azimuth of the current orthodrome relative to the meridian of the ground beacon.

Turn on the toggle switch "Plot" (plotting).

If the "plotted" azimuth and distance, projected on the PPDA-Sh, differ considerably from actual, projected by the RSBN, it is necessary to make a correction:

turn off toggle switch "Plot";

the "Correction" switch of unit P-14 is set in the position "RSBN-500."

On the navigator's signal panel the label "Coord. RSBN" will light up.

When the signals of the azimuth and distance of the RSBN are present in 3-5 s the label will go out and the correction of coordinates calculated in the NV will occur. After this it is necessary to turn off the correction switch of unit P-14.

If after this "plotting" the azimuth and distance again differ considerably from actual, one ought to check the correctness of the advanced data for correction and with the help of the other means to determine if there actually is a considerable error in the NV-PB in determining the present-position data of aircraft, whereupon correction from the RSBN is carried out.

#### The Correction of Calculated Coordinates of an Aircraft According to Airborne Radar

On the controllers of the correction coordinates of units P-6 and P-7 set the rectangular coordinates of the selected radar reference point relative to the current specified track.

The correction switch of unit P-14 is set in "RLV calc."

On the radar screen an electronic cross will be shaped in the form of an azimuthal mark and distance ring. The non-coincidence of the center of the cross with the mark of the selected reference point will be equal to error in determining the coordinates of the aircraft. With considerable errors one ought to make a correction of the coordinates of the aircraft;

the correction switch is set in the position "RLV corr.;"

with the control lever of the electronic switch combine the

center of the cross with the mark of the radar reference point on the screen of indicator;

based on the correction performed the correction switch is set in the "Off" position.

Approach to an Airfield with Calculation of the Coordinates of the Aircraft in the Mode "GO"

1. During approach to the first PPM of the entry corridor of the landing airfield or to the KPM at a distance of 50-70 km;

on the free scale of the master-indicator of the OZPU of unit P-12 set the magnetic heading of landing;

on the master-indicator of the PPM of units P-4 and P-5 set the rectangular coordinates of the PPM and KPM relative to the center of the RW of the landing airfield;

the switch "GO-Ch0" is set in the position "BO";

toggle switch "KR" is turned on.

2. During approach to the PPM at a distance of 15-20 km;

the toggle switch "KS" of unit P-14 is turned on;

on the master-indicators of the PPM of units P-4 and P-5 set the rectangular coordinates of the next PPM i. the zone of the airfield;

turn off toggle switch "KS."

3. During approach to the first point of the large rectangular route use the coordinates in the mode "GO" relative to the center of the RW based on the counters of current coordinates of units P-2 and P-3, on which the symbols "X" and "Y" are lit up.

#### THE NAVIGATION SLIDE RULE NL-10m

The purpose of the scales on the navigation computer (Fig. 95):

1, 2 - for the calculation of path time, of ground speed, for the solution of multiplication and division problems;

1a - for the calculation of the parameters of turn;

3, 4, 5 - for determining the trigonometric functions of angles, values of products  $a \sin \alpha$  and  $b \operatorname{tg} \beta$ , for the solution of navigational triangle by the theorem of sines, and for the calculation of the radius of turn (roll angle);

6 - for squaring and taking the square root (jointly with scale 5 or 1 and 2);

7, 8, 9 - for the recomputation of flight altitude at  $H < 12,000$  m;

10, 12, 14, 15 - for the recomputation of flight altitude at  $H > 12,000$  m;

11, 12, 14, 15, 16 - for the recomputation of airspeed with the usual (non-combined) speed indicator

11, 13, 14, 15, 16 - for the recomputation of airspeed with a combined speed indicator;

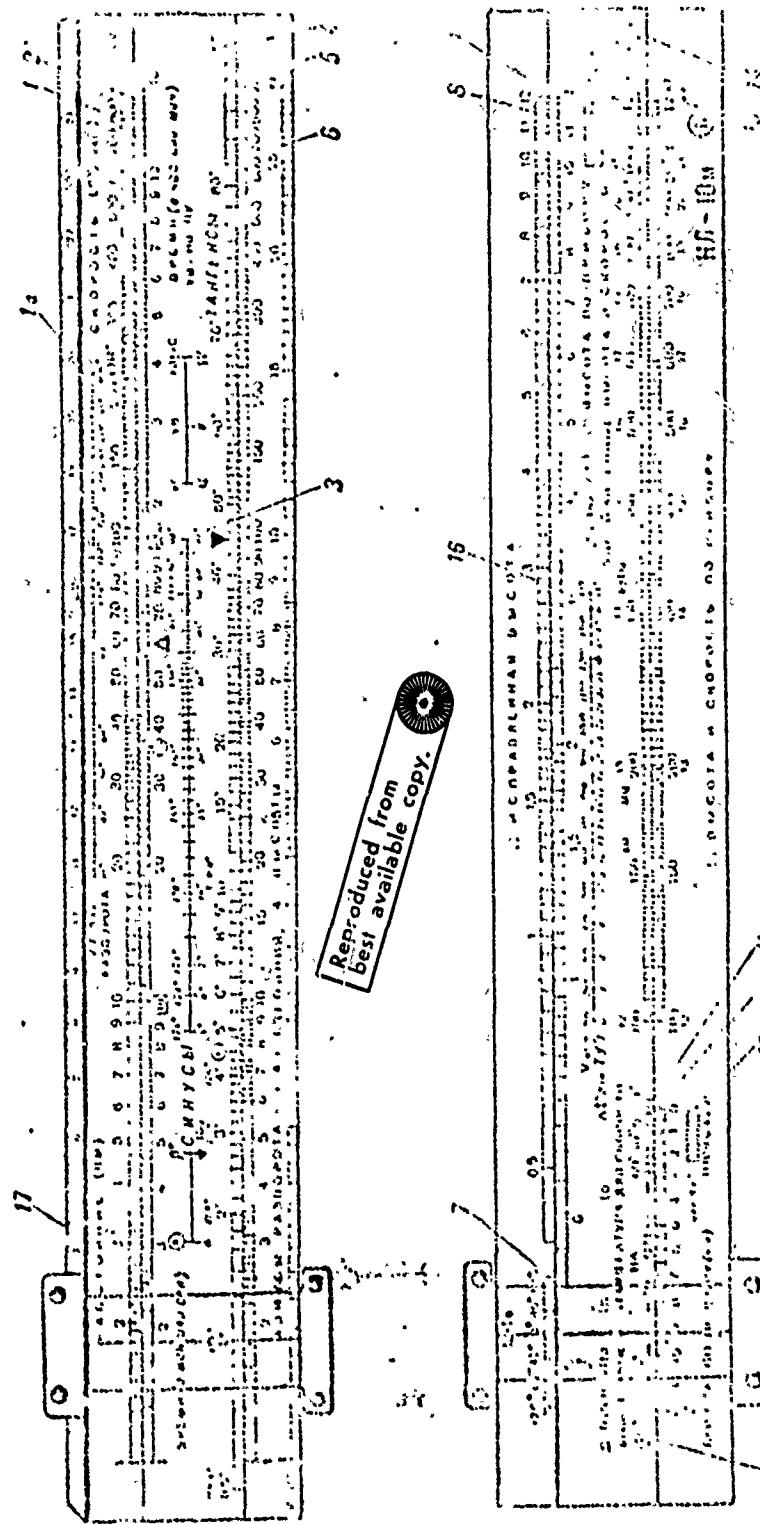


Fig. 2. The navigation computer N-16: (a) Range (km); (b) Time (hr or min); (c) Velocity (km/hr); (d) Angle of turn; (e) Sines; (f) Time (hr or min); (g) Tangents; (h) Secants; (i) Radius of turn; (j) Ranges; (k) Altitude; (l) Altitude; (m) Altitude; (n) Altitude; (o) Altitude; (p) Altitude; (q) Altitude; (r) Altitude; (s) Altitude; (t) Altitude; (u) Altitude; (v) Altitude; (w) Altitude; (x) Altitude; (y) Altitude; (z) Altitude.

17 - for the measurements of distances on a map.

The Solution of Basic Problems on  
the NI-10m

1. The calculation of horizontal range by height and slant range. Key - Fig. 96.

Example. Given  $ND = 26$  km;  $N = 9$  km [Translator's note:  
 $ND = ND$  and  $H = N$ ].

Find:  $\alpha = 20.2$  and then  $GD = 24.3$  km.

2. Determining the radius of turn based on angle of bank  
and rate of turn. Key - Fig. 97.

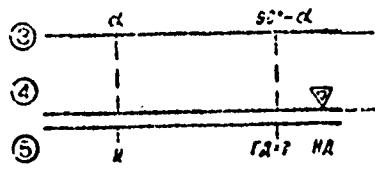


Fig. 96.

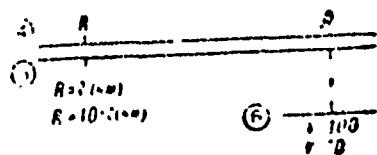


Fig. 97.

Example: 1. Given:  $V = 500$  km/h;  $\beta = 15^\circ$ . Find:  $R = 7.35$  km.

2. Given:  $V = 250$  km/h;  $\beta = 50^\circ$ . Find:  $R = 415$  m.

Note. Using the foregoing keys for the solution of problems,  
it is possible to find the value of any magnitude entering into  
the given problem based on two known values.

3. Calculation of the corrected altitude of flight accord-  
ing to the reading of a pressure altimeter.

Note. The value of temperature of height of flight taken from a thermocouple during all calculations of altitude and velocity must be corrected for the heat absorption of the sensitivity of the element of thermocouple according to scale 16 and calculated according to the formula found on the right of scale 16

$$t_{\text{hcmp}} = t_{\text{np}} - \Delta t.$$

For altitudes up to 12,000 m (Fig. 98).

Example. Given  $H_{\text{np}} = 2200$  m;  $t_0 = +25^\circ$ ;  $t_{\text{np} H} = +18^\circ$ ;  $V = 560$  km/h.

We find:

$$\begin{aligned} t_H &= t_{\text{np} H} - \Delta t = +18 - 9 = +9^\circ; \\ t_0 + t_H &= +25 + 9 = +34^\circ; \\ H_{\text{hcmp}} &= 2270 \text{ m.} \end{aligned}$$

4. The calculation of true airspeed according to the reading of a speed indicator for speed indicators of the type KUS-12" (Fig. 99) [Translator's note: HYC = KUS = combined airspeed indicator].

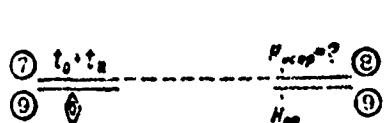


Fig. 98.

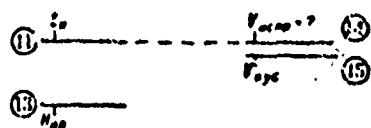


Fig. 99.

Example. Given:  $t_{\text{np} H} = +5^\circ$ ;  $V_{\text{HYC}} = 650$  km/h;  $H_{\text{np}} = 4500$  m. We find:  $t_H = +5 - 11 = -6^\circ$ ;  $V_{\text{hcmp}} = 660$  km/h.

5. Determining the time of turn and on an angle different from  $360^\circ$ .

**Example 1** (Fig. 100). Given:  $V = 500 \text{ km/h}$ ;  $R = 3000 \text{ m}$ ;  $\gamma_P = 100^\circ$ . We find:  $t_{360} = 2 \text{ min } 17 \text{ s}$ ;  $t_{\gamma_P} = 38 \text{ s}$ .

**Example 2** (Fig. 101). Given:  $t_{360} = 2 \text{ min } 17 \text{ s}$ ;  $\gamma_P = 60^\circ$ . We find:  $t_{\gamma_P} = 23 \text{ s}$ .

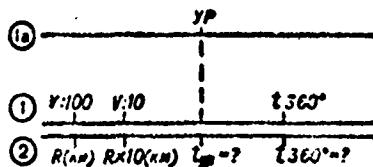


Fig. 100.

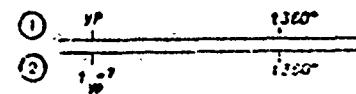


Fig. 101.

6. Determining the time of turn of an aircraft on  $360^\circ$  from the angle of the bank and rate of turn and on an angle different from  $360^\circ$ .

**Example 1** (Fig. 102). Given:  $V = 600 \text{ km/h}$ ;  $\beta = 20^\circ$ . We find:  $t_{360} = 290 \text{ s}$ .

**Example 2** (Fig. 103). Given:  $t_{360} = 290 \text{ s}$ ;  $\gamma_P = 110^\circ$ . We find:  $t_{\gamma_P} = 89 \text{ s}$ :

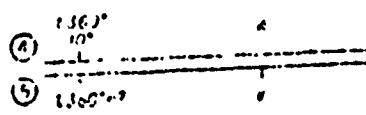


Fig. 102.

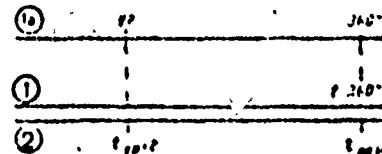


Fig. 103.

Determining the relationships between flight speed and M number with the help of the NL-10M

On scale 12 of the "Indicated altitude (km)" slide rule a graduation line is plotted which corresponds to the flight altitude 3250 m, the continuation of which is designated by a circular index. When the air temperature at the altitude of flight according to scale 11 "Temperature at altitude for speed" is set against this reference line, on scales 14 "Corrected altitude and speed" and 15 "Altitude and indicated airspeed" the relationship between air speed in kilometers per hour (scale 14) and M number (scale 15) is automatically calculated. On scale 15 the Mach number, equal to a unit, has a corresponding rectangular index with numbering 1000 (airspeed on scale 14 against this index is equal to the speed of sound).

In order to determine the speed of sound expressed in meters per second on scale 15 it is necessary to plot the graduation mark which corresponds to division 277.5, and designate it by index "a." Opposite this index according to scale 14 the speed of sound in meters per second is read off.

At the end of scale 14 it is necessary to place a supplementary designation "1" (true speed), while at the end of scale 15 - the designation "M."

Example. Air speed is limited by M number = 0.83, the air temperature at the flight height  $-45^{\circ}\text{C}$ , determine the maximum value of airspeed.

Solution. Opposite the round index on scale 12 we set the air temperature according to scale 11, equal to  $-45^{\circ}\text{C}$ . M number = 0.83 corresponds to an air speed of 900 km/hr. The speed of sound at this temperature is equal to 1085 km/hr, or 302 m/s.

Calculation of landing approach on a rectangular route with a left-hand turn in a cross wind from the moment of passing the outer marker beacon [DPRM]

1. Determine the value of the wind angle to the runway [RW] (ВПП) -  $\gamma_{B_{noc}}$  using the formula

$$\gamma_{B_{noc}} = \delta - \Pi_{MPU}.$$

[landing (magnetic) track angle [PMPU] (ПМПУ)]

2. Determine the value of the lateral component of wind velocity to the landing strip -  $\Delta U_6$  (Fig. 104)

$$\Delta U_6 = U \sin \gamma_{B_{noc}}.$$

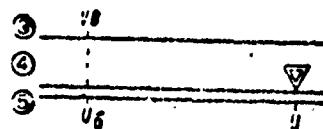


Fig. 104.

3. Determine the value of the counter component of wind velocity to the RW -  $\Delta U_5$  (Fig. 105)

$$\Delta U_5 = U \sin (90 - \gamma_{B_{noc}}).$$

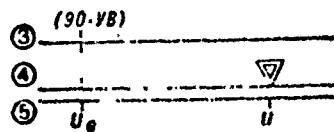


Fig. 105

4. Determine the value of the drift angle for a straight line from the beam of the outer marker beacon to the beginning of the third turn (Fig. 106)

$$\operatorname{tg} \gamma_{C_1} = \frac{\Delta U_6}{V}.$$

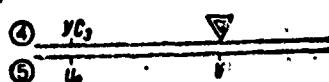


Fig. 106.

5. Determine the value of lead for the beginning of the third turn (Fig. 107)

$$t_{ynp} = \frac{\Delta U_s (t_{np} + t_{pass})}{W_{np}},$$

where  $t_{ynp}$  - lead time;

$t_{np}$  - flight time from the beam of the outer marker beacon in a calm;

$t_{pass}$  - time for the third turn;

$W_{np}$  - ground speed from the beam of the outer marker beacon before the beginning of the third turn ( $V_H + V_S$ ).

6. Determine the time of onset of the third turn using the formula

$$t_{start, pass} = t_{start, pass, mr} - t_{ynp}.$$

7. Determine the value of the drift angle for a straight line from the third to the fourth turn -  $US_3$  [ $yC_3$ ] (Fig. 108)

$$\operatorname{tg} yC_3 = \frac{\Delta U_s}{V}.$$

8. Determine the value of magnetic course for a straight line from the third to the fourth turns -  $MK_3 = MPU_3$  [ $MNY_3$ ] -  $US_3$ .

9. Determine the KUR for the beginning of the fourth turn -  $KUR_4$  by the formula

$$KYP_4 = KYP_{mr} + yC_3 \pm (\Delta_{KYP}).$$

$\Delta_{KUR}$  - is determined on the NL-10 (key see on Fig. 109),

where  $S$  - the distance from the beam of the outer marker beacon to the straight line between the third and fourth turns;

BU [БУ] - (lateral deviation) - the product of the time of turn ( $t_{\text{пос}}$ ) by the lateral component of wind velocity to the landing pattern ( $\Delta U_6$ );

$\Delta_{\text{KUR}}$  - is taken with the "plus" sign at  $\Delta U_6$  incidental and "minus" - at  $\Delta U_6$  counter to the straight line from the third to the fourth turns.

10. Determine the value of the drift angle for the last straight line -  $\text{YC}_{\text{noc}}$  (Fig. 110).

$$\text{tg } \text{YC}_{\text{noc}} = \frac{\Delta U_6}{V_{\text{cp}}}.$$

11. Determine the value of the magnetic course for the last straight line -  $\text{MK}_{\text{noc}}$  using the formula

$$\text{MK}_{\text{noc}} = \text{ПМПУ} - \text{YC}_{\text{noc}}.$$

12. Determine the distance to the RW from the entrance point to the glide path -  $S_{\text{TBГ}}$  (Fig. 111)

$$S_{\text{TBГ}} = \frac{H_{\text{ex. гл}}}{\text{tg } \text{УНГ}}.$$

[ $\text{TBГ}$  - entrance point to glide path]

where  $H_{\text{ex. гл}}$  - altitude of entry to glide path;

UNG [ $\text{УНГ}$ ] - angle of tilt of glide path.

13. Determine the time of flight from the outer marker beacon to the RW -  $T_{\text{пос}}$  (Fig. 112)

$$T_{\text{пос}} = \frac{S}{V_{\text{cp}}}.$$

14. Determine the vertical rate of descent from the outer marker beacon to the RW (Fig. 113)

$$V_{\text{спр}} = \frac{H}{t}.$$

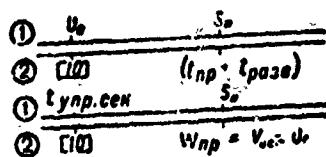


Fig. 107.

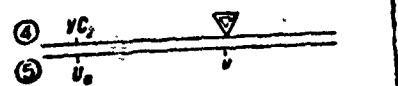


Fig. 108.



Fig. 109.

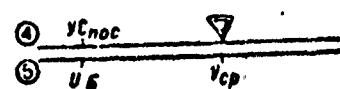


Fig. 110.

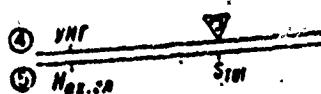


Fig. 111.

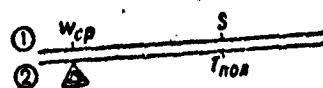


Fig. 112.

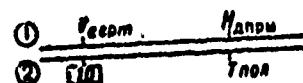


Fig. 113.

## NRK-2 NAVIGATIONAL COMPUTER

### Purpose and performance data

The NRK-2 navigational computer developed by M. V. Kalashnikov is a computing instrument intended for making navigational calculations during preflight operations and in flight.

With the help of the navigational computer the following problems are solved:

the calculation of drift angle, ground speed, the angle between course and wind direction, flight course or actual track course based on the known wind vector;

determining wind from the known angle of drift and ground speed, from two drift angles, and from two ground speeds;

determining the route traversed, speed, and flight time;

determining the radius and time of turn on assigned angle based on known velocities and angle of bank; recalculation of true speed into instrument and instrument into true in the range of 100-2500 km/hr;

determining the M number which corresponds to the assigned flight speed and vice versa;

determining the correction for air compressibility into readings of the wide points on the aerodynamic speed indicators;

conversion of true altitude into indicated and indicated into true in the range of 100-25,000 m;

determining the values of trigonometric functions, multiplication and division of numbers into the trigonometric functions of angles.

Furthermore the navigational computer makes it possible to carry out some other mathematical calculations, and also to convert nautical and English miles into kilometers, feet into meters, millimeters of mercury column into millibars, degrees into radians, and vice versa.

The over-all dimensions of the navigational computer are 130 x 11 mm.

Table 29. Scales and nomograms on the NRK-2.

No. of scales	Name (purpose) of the scale or nomogram	Intervals of graduation of the scales	Scale value	
			Smallest	Greater
1	Speed (km/h).....	1-2,500 km/h	0.1 km/h	50 km/h
2	Tangents of angles.....	1-85°	1°	1°
3	Percentages: of relative ground speed of relative wind velocity.....	70-130% 4-30%	1% 0.1%	1% 1%
4	Rate/velocity.....	1-2,500 km/h	0.1 km/h	50 km/h
	Route.....	1-2,500 km	km	km
5	Time: in seconds and minutes.. in minutes and hours....	1-100 min (s) 1-10 h	1/6 s 1.0 s	0.5 min 0.5 h
	Nomograms: a) concentric circles for the reading of relative wind vectors.....	0-30%	1%	5%
	b) arcs for the reading of relative vectors of ground speed.....	70-130%	1%	5%
	c) vertical lines for the reading of drift angles.....	0-17°	1°	5°
	d) heading line.....	70-130%	1%	5%
	e) scales for angle between course and wind direction (KUV).....	0-360°	10°	30°
	f) scale for wind disk..	0-30% or m/s	1% (m/s)	5% (m/s)
6	Sines of angles in degrees	6-90°	1°	1°
7	True air speeds.....	100-2,500 km/h	2 km/h	50 km/h
8	Indicated, equivalent airspeeds and M numbers...	100-2,500 km/h	2 km/h	50 km/h

Table 29. Scales and nomograms on the NRK-2. (Continued)

No. of scale	Name (purpose) of the scale or nomogram	Intervals of graduation of the scales	Scale value	
			Smallest	Greatest
9	Correction in the readings of the electrical outside-air temperature gauges: for TUE..... for TNV.....	4-100° 2-140°	2° 22°	10° 20°
10	Indicated altitudes.....	0-11 km	1 km	1 km
11	Indicated altitudes.....	0-25 km	0.5 km	0.5 km
12	Indicated altitudes.....	0-11 km	1 km	1 km
13	Values of outside air temperature.....	From +30 to -80°	10°	10°
14	Correction in speed for compressibility of air...	10-170 km/h	10 km/h	10 km/h
15	Indicated airspeeds.....	400-1,300 km/h	100 km/h	100 km/h
16	Indicated altitudes.....	2-25 km	1 km	1 km
17	Values of the true or corrected barometric height less than 12,000 m	10,0-12,000 m	100 m	100 m
18	Indicated altitudes.....	1000-12,000 m	100 m	100 m
19	Indicated altitudes.....	100-1200 m		10-50 m
20	Sums of the air temperatures at the ground and at that altitude.....	From +80 to -120°	10°	10°
21	Air temperature at that altitude.....	From -30 to -90°	20°	20°
22	Values of the true or corrected altitude above 12,000 m.....	12,000-25,000 m	100 m	200 m
23	Values of indicated altitude above 12,000 m	12,000-25,000 m	100 m	200 m

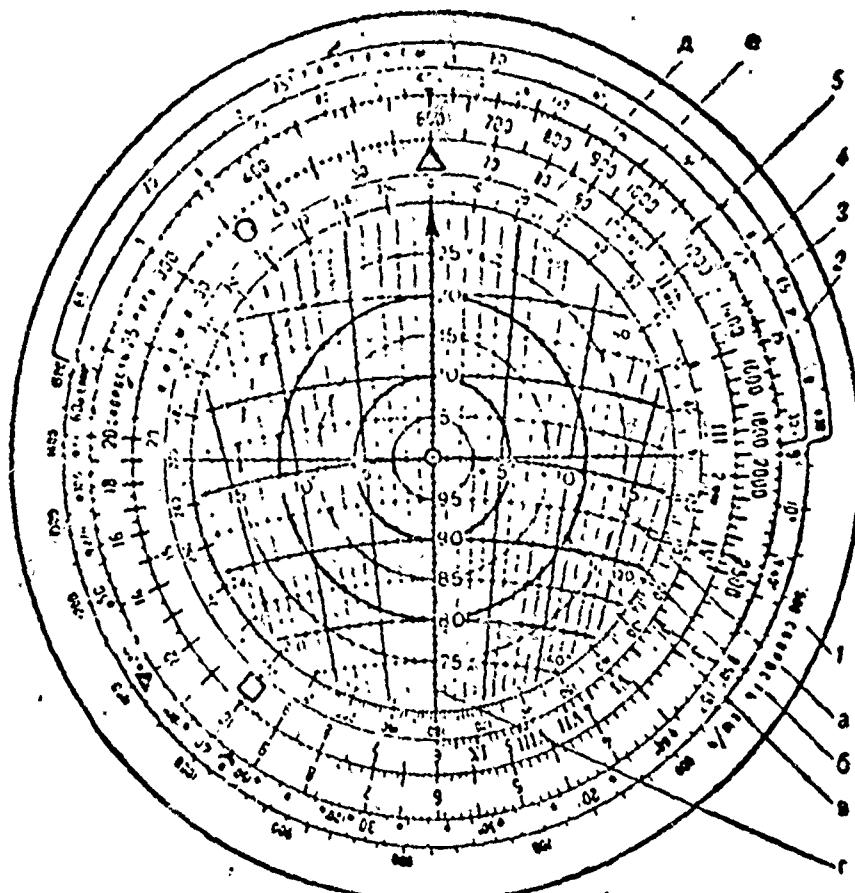


Fig. 114. Face side of the NRK-2.

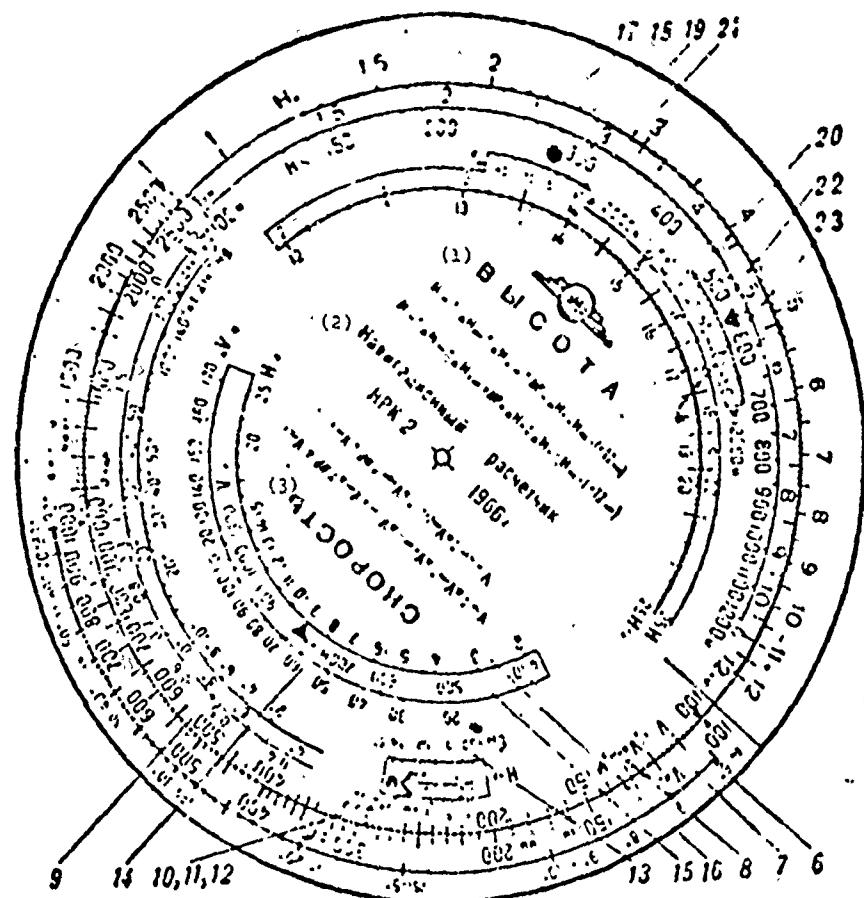


Fig. 115. Back side of the NRK-2.  
KEY: (1) Altitude; (2) Navigational computer;  
(3) Speed.

## Construction and the principles of operation

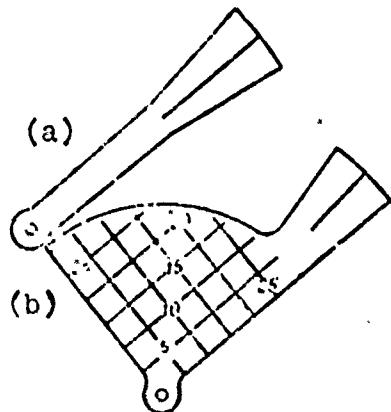
The NRK-2 navigational computer (Fig. 114, 115) consists of four disks which rotate around a common axis. The disks have logarithmic and other scales and a nomogram plotted on them and also indices and transparent windows for reading the corresponding scales of assigned or desired values. One disk is the base navigational computer, scales are plotted on both sides, the other disks (two - on the face side, one - on the reverse) have a smaller diameter and are movable. For reading there are aiming rules (Fig. 116).

On the face side of the navigational computer (see Fig. 114) on the base and on the two rotating disks there are scales, nomograms, and indices which form a drift computer and ensure the graphical solution of the navigational velocity triangle.

The principle of solution of navigational velocity triangle on the drift computer of the NRK-2 is based on the fact that the vectors of air and ground speeds and wind are represented in relative values. Thus the vector of airspeed  $\bar{V}$  is accepted as 100%, and the vectors of ground speed  $\bar{W}$  and wind  $\bar{U}$  correspondingly as

$$\frac{\bar{W}}{\bar{V}} \cdot 100 \quad \text{and} \quad \frac{\bar{U}}{\bar{V}} \cdot 100.$$

Fig. 116. Rules for the rule (a) and face (b) sides of the NRK-2



Signs and indices on the face side  
of the computer

- round indices, colored black on a gray movable disk on scale 2 (tangents) for determining the turning time of an aircraft on any angle up to  $360^\circ$ 
  - $90^\circ$
  - $1360^\circ$
- triangular index on scale 5 (time) serves for the solution of problems connected with determining the flight time, distance covered, and ground speed. Corresponds to a division of 60 min or 1 h (60 s or 1 min)
  - 
- triangular index, colored black against a gray background on scale 2 (tangents), which corresponds to a division of  $45^\circ$  for the solution of problem with the trigonometric functions of the tangents of angles.
  - 
- figure index, colored black on scale 2 (tangents), serving for the solution of problems on the determinations of radii of turn of the aircraft
  - 
- rectangular index on scale 5 (time) is used as the initial prime of the scale
  - 
- circular index on scale 5 serves for the conversion of velocity expressed in km/h into velocity expressed in m/s. It corresponds to a division of 36 (3.6).
  - 

On the back side of the computer



- triangular indices. Upper - on the base of the computer, lower - on the gray movable disk on scales 7 and 8. They serve for the designation of decimal

intervals of the scales and are used during multiplication and division of numbers

am mm - indices on the base of computer on scale 7 for the conversion of kilometers into English and nautical miles and vice versa

$\pi$  - index of the relationship of the circumference length to the radius on scale 7, used when determining the circumference length

$\phi$  - index on scale 7, used for the conversion of feet into meters and vice versa

a m/s - index on scale 8 for determining the speed of sound in m/s

a km/h - index on scale 8 which corresponds to M-1 number. Airspeed against this index, equal to the speed of sound in km/h, is calculated according to scale 7

$\diamond$  - rhombic index on scale 18 which corresponds to a division of 11,000 m and serves for determining H

$\downarrow$  - triangular index colored black on scale 19. Is installed for reading scale 20, which corresponds to the sum of the temperatures at the ground and at the altitude of flight

$\odot$  - circular index on scale 21 which corresponds to temperature at altitude of flight

- ▷ M - figure index on the base of the computer on scale 17, serving for determining of M number based on assigned airspeed and vice versa
- ▷  $H_{\text{bar}}$  - figure index on the base of the computer on scale 15, serving for determining the correction in velocity for compressibility
- mm Hg cm - index on the basis of the computer on scale 7, serving for the conversion of millibars into mm Hg and vice versa.

On the rotating disk of the back side, furthermore, there are formulas, by which the conversion of altitude and speed is conducted. The upper row of signs in the formulas is used in the conversion of the indicated values into true, the lower row - during the conversion is conducted with the navigational computer's help.

#### The order of solution of problems

1. The conversion of speeds expressed in km/h into the speeds expressed in m/s, and vice versa, and also the calculation of sweep, speed and flight time is accomplished by the same rules as on the NL-10m with the help of scales 4 and 5 (see Fig. 115).
2. Calculation of the flight course and ground speed based on the known wind vector.

On the wind computer set the triangular index of time scale 5 on the division of speed scale 4 which corresponds to the

value of assigned airspeed  $V$  km/h. On the scale of percentages<sup>1</sup> based on the wind velocity  $U$  km/h determine the value of relative wind velocity  $U\%$  (or  $U/V \cdot 100$ ).

Expand the course dial so that opposite the pointer of the course line of the nomogram the division of the course scale which corresponds to the magnetic wind bearing  $\delta$  would be set, and opposite the division of the heading line which corresponds to  $U\%$ , on the dial with a pencil place a mark which is the end of relative wind velocity.

Opposite the pointer of heading line set the value of given magnetic course angle (ZMPU). On the nomogram opposite the mark which was made count off the value of the drift angle (US). Determine the assigned heading of the aircraft by the formula  $ZMK = ZMPU = US$  and set it opposite the pointer (or expand the dial on the hour hand - in the case of right drift, opposite the hour hand - in the case of left by the value of the US). Opposite the wind mark, using lines  $a$  and arcs  $b$  of the nomogram, measure off the refined values of US and relative ground speed<sup>2</sup>  $W\%$ . (If the new value of drift angle is different from the first by more than  $1^\circ$ , set the magnetic heading taking this US into account opposite the pointer of the heading line.)

---

<sup>1</sup>The scale of percentages has numbered divisions from 4 to 30, and the divisions which correspond to 7, 8, ..., 13, are numbered respectively 70, 80, ..., 130 and the intervals between them are divided into ten parts. Thanks to this with the help of the scale it is possible to convert the values of relative ground speed  $W\%$  (or  $W/V \cdot 100$ ) into absolute values and vice versa within the limits of 70-130%, and  $U\%$  within the limits - 1-30% (for example, opposite the division 100% the velocity which corresponds to 1 and 10% can be measured off).

<sup>2</sup>Divisions on the upper part of the heading line of the nomogram are enumerated 5, 10, ..., 25%, which when reading values relative to ground speed correspond to 105, 100, ..., 125%.

Having checked that the triangular index of the time scale is set at the value of airspeed, from the value of  $W\%$  obtained with the help of the scale of percentages determine the value of ground speed in km/h.

Example. Given: the  $V = 900$  km/h;  $\delta = 85^\circ$ ;  $U = 120$  km/h;  $ZMPU = 335^\circ$ . Find:  $U\% = 13\%$ ;  $US + 7^\circ$ ;  $W\% = 95\%$ ;  $W = 885$  km/h;  $MK = 328^\circ$ .

3. The calculation of actual track angle and ground speed based on a known wind vector.

Set the triangular index of the time scale on the division of the velocity scale which corresponds to actual airspeed. With the help of the scale of percentages on  $U$  km/h determine  $U\%$ . Opposite the pointer of the heading line set the division which corresponds to the magnetic bearing of the wind, and, having noted the end of the vector of relative wind velocity, set the value of the average actual (or calculated) magnetic course. Measure off against the mark on the nomogram the value of the drift angle in degrees and the value of relative ground speed, after which with the help of the scale of percentages determine the value of ground speed in km/h. The actual (calculated) magnetic course angle is determined from the formula  $FMPU = FMK + US$ . [ $FMPU$  = actual magnetic course angle].

4. Calculation of wind according to ground speed and angle of drift.

Set the triangular index of the time scale at the value of airspeed. With the help of the scale of percentages based on  $W$  km/h determine the value of  $W\%$ . Opposite the pointer of the course line set the mean value of the magnetic flight course and based on the values of  $W\%$  and  $US$  plot on the course dial a mark which will be the end of the vector of relative wind velocity.

Expand the course dial to agreement of the mark made with the course line, measure off the values of magnetic bearing and relative wind velocity  $U\%$ , whereupon with the help of the scale of percentages determine  $U$  km/h.

5. Calculation of wind according to two drift angles measured on two courses.

Set the triangular index of the time scale on the value of airspeed, and opposite the pointer of course line - the mean value of the first magnetic heading. Along the line of the nomogram which corresponds to the value of the first measured US draw a line with a pencil on the course dial. Having established the mean value of the second magnetic heading, draw a line which corresponds to value of the second US. The pointer of intersection of the lines is the end of the vector of relative wind velocity. Direction and wind velocity km/h are determined just as in p. 4.

6. Calculation of wind according to two ground speeds determined on two courses.

Set the triangular index of the time scale on the value of airspeed and with the help of the scale of percentages based on known values of  $W_1$  and  $W_2$  in km/h determine  $W_1\%$  and  $W_2\%$ . Opposite the pointer of the course line set the mean value of the first magnetic course and on the course dial draw an arc which corresponds to the value  $W_1\%$ . Set the mean value of the second magnetic course and draw an arc which corresponds to the value  $W_2\%$ . The point of intersection of arcs is the end of the vector of relative wind velocity. Direction and wind velocity in km/h are determined just as in p. 4.

7. Determining the longitudinal and transverse components of the wind vector.

The problem is solved with the help of a rectangular grid applied on the sector of the aiming rule. For this first it is necessary to set the triangular index on the value of airspeed and to plot, as shown in p. 2, on the course dial the vector of relative wind velocity. Having established the magnetic course, for which it is necessary to determine the wind component, combine the movable sector with the sector on the nomogram in which the wind vector is found. With the help of rectangular grid determine the wind component in percentages and their signs. Component wind velocities in km/h are determined with the help of the scale of percentages.

8. Determining the vector by its longitudinal and transverse components.

Set the triangular index of the time scale on the value of airspeed, and opposite the pointer of the course line - the value of the magnetic course to which the values of wind components correspond. With the help of the scale of percentages determine the relative longitudinal and transverse components of wind velocities. Combine the movable sector with the sector on the nomogram in accordance with the signs of components; using a rectangular grid based on the values of relative components plot on the sector the mark which is the end of the vector of relative wind velocity.

The magnitude of relative wind velocity can be determined with the help of concentric circles, and the velocity in km/h - with the scale of percentages. The wind direction is measured off on the course scale, having continued with a pencil the wind vector up to the edge of the sector.

9. Determining the correction in the readings of the outside-air temperature gauges of the type TUE and TNV.

Corrections are measured off on scale 9 (see Fig. 115) against the values of true airspeed on the scale of velocities 8.

10. Calculation of the true flight altitude according to the readings of a barometric altimeter and, on the contrary, below 12,000 m.

The account of the systematic error in the altitude indicator which appears as a result of the nonconformity of the actual air temperature at altitude of flight to the standard value is conducted just as on the NL-10m. For this scales 17 and 20, 18 and 19 and the triangular index are used.

The formulas, which are applied on the rotating disk, show the order of solution of problems on the conversion of altitudes and velocities. The upper row of signs in the formulas is used in the conversion of indicated values into true (the course of solution is from left to right), the lower row - in the conversion of true values into indicated (the course of solution - from right to left). The designation "NR" shows that henceforth the conversion is conducted with the help of the NRK-2.

11. Calculation of the true altitude of flight according to the readings of a barometric altimeter and, on the contrary, for altitudes greater than 12,000 m.

Systematic error is considered with the help of scales 3 and 21, 23, and the triangular index, just as on the HL-10m.

The correction  $\Delta H_{11}$ , which considers the deviation of the position of the tropopause from the standard value, equal to 11,000 m, is determined with the help of scales 17, 20, and the triangular and rhombic indices on scale 18. For this opposite the triangular index set the value of the sum of the temperatures at the earth and at altitude of flight. The rhombic index will indicate the magnitude and sign of the correction  $\Delta H_{11}$  reckoned

on the scale  $H_H$  (17) to the right and to the left from the division which corresponds to 11,000 m.

12. Calculation of the true flight speed according to the readings of the airspeed indicator and vice versa.

The account of the systematic error of the wide pointer of the speed indicator which appears as a result of the nonconformity of the actual air temperature at the altitude of flight to its standard value is fulfilled with the help of scales 7 and 11, 8, 13 or 12 on the computer.

If flight is performed at a speed greater than 400 km/h and altitude above 5000 m, then during the conversion of velocities it is necessary to consider the correction for air compressibility. In this case (just as on the NL-10 m) on scale 8 the value of equivalent, and not indicated airspeed is set or measured off, i.e., the velocity not allowing for correction for air compressibility.

Correction for air compressibility is determined on the navigational computer the the help of scale 15, the figure index and scales 14 and 16. For this it is necessary that opposite the figure index " $H_{np}$ " the division is set which corresponds to the indicated flight altitude, and opposite the value of indicated airspeed read off the value of correction.

The order of calculating the correction is shown by the formula, applied on the rotating disk.

13. Calculation of the true velocity of flight according to the readings of the narrow pointer of the KUS and vice versa.

Systematic error is considered with the help of scales 7, 10, 8 and 13 just as on the NL-10 m.

14. Determining the M number according to the value of true flight speed.

The problem is solved with the help of scale 10 and index 13 and scales 8, 13, or 12. For this opposite index "M" 13 set the value of actual air temperature on scale 13 or indicated altitude on scale 12. Opposite the division which corresponds to true airspeed in km/h (on scale 7), read off on scale 8 the value of M number.

In the same order the true airspeed is determined based on M number.

15. Determining the radius of turn with an assigned angle of bank and speed on the turn.

The radius of turn is determined with the help of scales 1, 4 and the scale of tangents 2. For this set the value of bank angle according to the scale of tangents opposite the value of true speed in km/h on scale 2. Opposite index "R" on the distance scale 4 read off the value of the radius of turn in kilometers.

Determining the bank angle from a known radius and flight speed on the turn is the reverse problem.

16. Determining the time of turn on an assigned angle with assigned bank and speed.

The time of turn on an assigned angle is determined with the help of scale 4, the scale of tangents 2 and the indices marked on it. For this the division of the tangent scale which corresponds to the value of assigned bank is set opposite the value of airspeed in hundreds of kilometers per hour on scale 1. Opposite the index which corresponds to the value of the angle of turn read off the time of turn in seconds or tens of seconds.

17. It is more convenient to carry out the multiplication and division of numbers with the help of the logarithmic scales of true and equivalent speeds 7 and 8.

18. The squaring of numbers and extraction of square root from numbers is possible with the help of scales 1 and 4.

19. Determining the values of trigonometric functions, multiplication and division of number into trigonometric functions of angle and the solution of a right triangle is conducted with the help of the scales of sines and tangents and their adjacent scales.

20. The conversion of nautical and English miles into kilometers, feet into meters, and millimeters of mercury column into millibars and back is carried out with the help of scale 7 and the indices plotted on it and scale 17. For this it is necessary to set against one of the indices (mm, am, lb, mm Hg) the division 100 and 1000 of the scale of equivalent airspeeds 6. In this case on the lower scale the values expressed in miles, feet, or millimeters Hg are read, on the upper - respectively in kilometers, meters, or millibars.

For the conversion of degrees into radians division 180 is set opposite the index.

Example of the calculation of actual flight altitude higher than 12,000 m based on the readings of barometric altimeters.

Given:  $H_{np} = 15,000$  m;  $\Delta H_{nac} = -150$  m;  $\Delta H_{sep} = +250$  m;  $\Delta H_p = +400$  m;  $t_H = -70^\circ$ ;  $t_o = -10^\circ$ .

Solution. 1. Into the reading of indicated altitude, taken from the barometric altimeter, corrections are introduced for the instrument and for the excess of the airfield relative to sea level:

$$H_{\text{нсп}} = H_{\text{пр}} = \Delta H_{\text{ннс}} + \Delta H_{\text{аэр}} = 15,000 + (-150) + (+250) = 15,600 \text{ м.}$$

2. Into the altitude obtained a systematic correction is introduced with the help of the navigational computer and a result of 15,300 m is obtained.

3. Into the altitude obtained a correction is introduced for the excess of terrain relative to the airport of departure and the corrected altitude  $H'_{\text{нсп}}$  is obtained

$$H'_{\text{нсп}} = 15,300 - (-400) = 15,700 \text{ м.}$$

4. A supplementary correction  $H$  is determined from the formula

$$\Delta H_{11} = 900 - 20(t_a - t_H) - \frac{900}{204 - 10 - 70} = -700 \text{ м.}$$

This correction can be calculated on a navigational computer and with a great deal of accuracy. For this, having set the triangular index of scale 19 on the sum of temperatures on scale 20, on scale 17 one should take a reading  $H_{\text{нсп}} = 10,150$  m. Then correction  $\Delta H_{11}$  is found. It will be equal to:

$$\Delta H_{11} = H_{\text{нсп}} - 10,150 = -10,150 + -850 = -11,000 \text{ м.}$$

5. With the introduction of correction  $\Delta H_{11}$  into the resulting altitude  $H'_{\text{нсп}}$  the value of the desired flight altitude is obtained:

$$H_{\text{нр}} = H'_{\text{нсп}} + (-850) = 14,900 \text{ м.}$$

Calculation of magnetic flight course, drift angle, ground speed, and the angle between course and wind direction according to a known wind vector

For the solution of this problem it is necessary to know the following data:

$V_n$  - true airspeed;  
ZMPU - given magnetic course angle;  
 $\delta$  - wind direction;  
 $U$  - wind velocity.

When solving the problem with the help of a navigational computer the following scales are used: 4 - route and velocity, 5 - time, 3 - percentages, course angles of wind disk, nomogram of the base of the computer, transparent wind disk, and the triangular index of scale 5.

The order of solution:

1. By rotation of the movable disk the triangular index of scale 5 is set at the value which corresponds to the calculated true velocity  $V_n$  km/h according to scale 4. The thread of the aiming rule is set according to scale 4 on a reading equal to wind velocity  $U$  km/h, and opposite this reading, according to scale 3 (percentages), relative wind velocity is determined

$$\frac{U}{V} = U\%$$

2. The transparent wind disk is turned so that the division of the course scale of the disk which corresponds to the magnetic bearing of wind  $\delta^\circ$  is set opposite the course line of the nomogram and on the course line of the nomogram, computing on concentric circumferences a, with a pencil a point is plotted which determines the end of the vector of relative wind velocity  $U\%$ .

3. By rotation of the wind disk the division which corresponds to assigned magnetic course angle is set opposite the course line. As a result the point of the end of relative vector will be misaligned and opposite it on nomogram on straight lines "b" the drift angle (US) is read off.

4. The wind disk is turned to the right in the case of right drift, to the left - in the case of left drift by the value of the US obtained. Opposite the course line of the nomogram the value of the calculated magnetic heading ( $MK_{pac4}$ ) is read. Opposite the end of the relative wind vector the value of the refined drift angle is counted off. From the point of the end of relative wind vector mentally a line is drawn parallel to arcs "b," on the course line the value of relative ground speed in percentages (W%) is read off, and on the scale of course angles of the nomogram - the angle between course and wind direction (KUV). Opposite the value W% obtained, which is located on scale 3 (percentages), below on scale 4 the desired W km/h is read.

Example.

Given:  $V_H = 750$  km/h;  $\delta = 146^\circ$ ; ZMPU - 262;  $U = 130$  km/m.

Solution:  $U\% = 17.2\%$ ;  $W\% = 91\%$ ;  $US = -10^\circ\%$ ;  $MK_{pac4} = 272^\circ$ ;  $W = 680$  km/h;  $KUV = 235^\circ$ ; refined  $US = -9^\circ$ .

Note. A detailed description of the navigational computer and a large number of examples which illustrate the operation with it are given in the textbook "Navigational computer NRK-2," compiled by I. M. Baranovskiy.

#### NOMOGRAMS AND CHARTS, THEIR USE IN AVIATION

It is convenient to use nomograms when it is necessary to repeatedly perform a computational operation of one and the same kind, but each time with different numerical data.

For addition and subtraction of any physical quantities it is possible to compile nomograms of two types.

1. If any physical quantities (for example the speed of the aircraft and the incidental or counter component of wind velocity)  $x$  and  $y$  (Fig. 117), measured with the help of some scale, are plotted on the appropriate coordinate axes, then under the condition  $AC = y$  and  $AO = x$  slopes drawn from point  $C$  at angles of  $45^\circ$  toward the  $x$  axis will intercept segments  $x + y$  and  $x - y$  on it.

If on millimeter graph paper we draw a family of slopes, then we will obtain a nomogram for addition and subtraction. For using the nomogram there is no need to draw new lines, but it suffices with the tip of a pencil to follow those already made.

2. If on two parallel lines 1 and 2 (Fig. 118), beginning from zero line MN, we plot in the form of segments measured with the help of the same scale, the value  $x$  and  $y$ , which are to be added, then straight line AB will cut off on the third parallel line, passing in the middle between straight lines 1 and 2, the segment LC, equal to  $\frac{x+y}{2}$ . Straight line DK, drawn parallel to AB, will cut off on scale 1 a segment equal to  $x - y$ . All three parallel lines are called the scales, and points A, B, and C - the adjusted points.

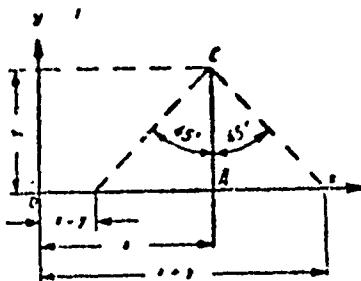


Fig. 117.

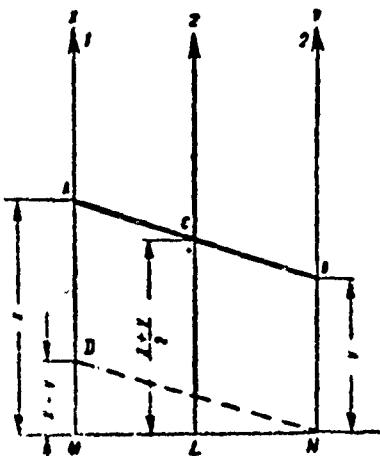


Fig. 118.

In order to read immediately on straight line LZ the desired answer  $x + y$ , and not  $\frac{x+y}{2}$ , it is necessary to take for it a different scale than for straight lines 1 and 2.

Example.  $x$  and  $y$  have been plotted to a scale of 1 cm = 20 km/h. If for straight line LZ we take a scale of 40 km/h, then on it we will immediately have the desired answer.

The first method is called the grid method, the second - the method of adjusted points.

Multiplication and division are performed in the following manner: the values  $x$  and  $y$  being multiplied are plotted as usual on the X and Y axes (Fig. 119). From the terminal point of segment X a perpendicular is erected to axis X and is continued to its intersection with a horizontal line drawn parallel to axis X at a distance  $y = 1$ . The intersection of the extension of ray OC with a horizontal line drawn from a point which corresponds to value  $y$  give us the desired  $xy$  value.

In addition and subtraction it is possible to operate only with values given in the same measurements. It is possible to multiply and divide the values which are measured by heterogeneous measures.

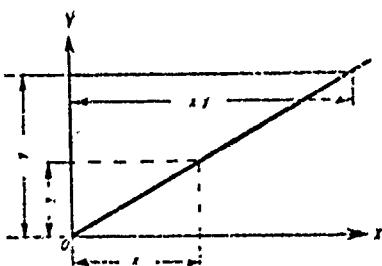


Fig. 119.

With the help of the logarithmic operation multiplication can be reduced to addition, and division - to subtraction. For this on the scales (see Fig. 118) we plot not the numbers themselves, but the so-called "dividing points" which correspond to the logarithmic values of the numbers. However, at the points of division obtained in a special manner the logarithms of numbers are not written but the logarithmized numbers themselves. Such scales are called functional scales (Fig. 120). If scale LZ passes strictly along the middle between functional scales 1 and 2, then, on the strength of the fact that on it the results of the multiplication of numbers  $x$  and  $y$  are found, the squares of the numbers which correspond to the divisions of numbers of scales 1 and 2 lie at the points of intersection of scale LZ with the horizontal lines which connect the identical divisions of scales 1 and 2. In order to find sum or difference, product or quotient, when using a prepared nomogram there is no need to draw the connecting straight line AB, but it is simpler to add a ruler or a tightly drawn thread.

Since with the help of a nomogram not only the simplest problems of addition and subtraction, multiplication and division, raising to a power and root extraction are solved, but also the more complex problems of the graphical solution of numerical equations with any coefficients, in aviation nomograms have received wide distribution.

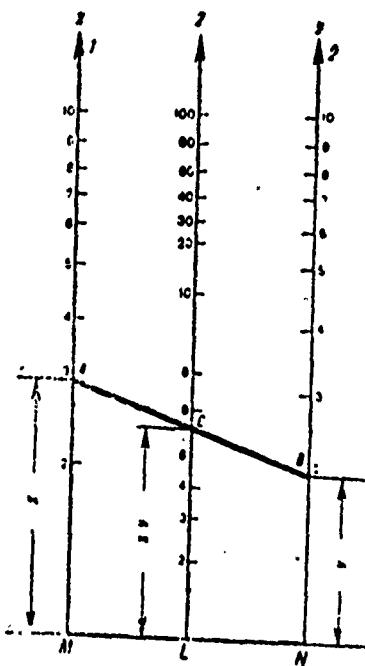


Fig. 120.

A number of values determined during aircraft tests by experiment can be plotted on nomograms in the form of a family of curves. This considerably increases the field of application of the nomogram. Still more expanded are the possibilities of their use by the introduction of nomogram with auxiliary scales.

In their daily operation not one crew on a turbojet can manage without the use of nomograms for determining the takeoff and landing runs taking into account meteorological conditions, at various take-off weights, on concrete and on soil, at different state and gradient of RW, etc. Nomograms are also used for determining the required distance of a prolonged takeoff (Fig. 121) depending on the takeoff conditions and a number of others.

Examples 1. Initial data:  $t_0 = 0^\circ \text{C}$  (1),  $p_0 = 760 \text{ mm Hg}$  (2),  $G_{B3n} = 21 \text{ T}$  (3), counter wind component  $W = 4 \text{ m/s}$  (4), slope  $\gamma = 0$  (5).

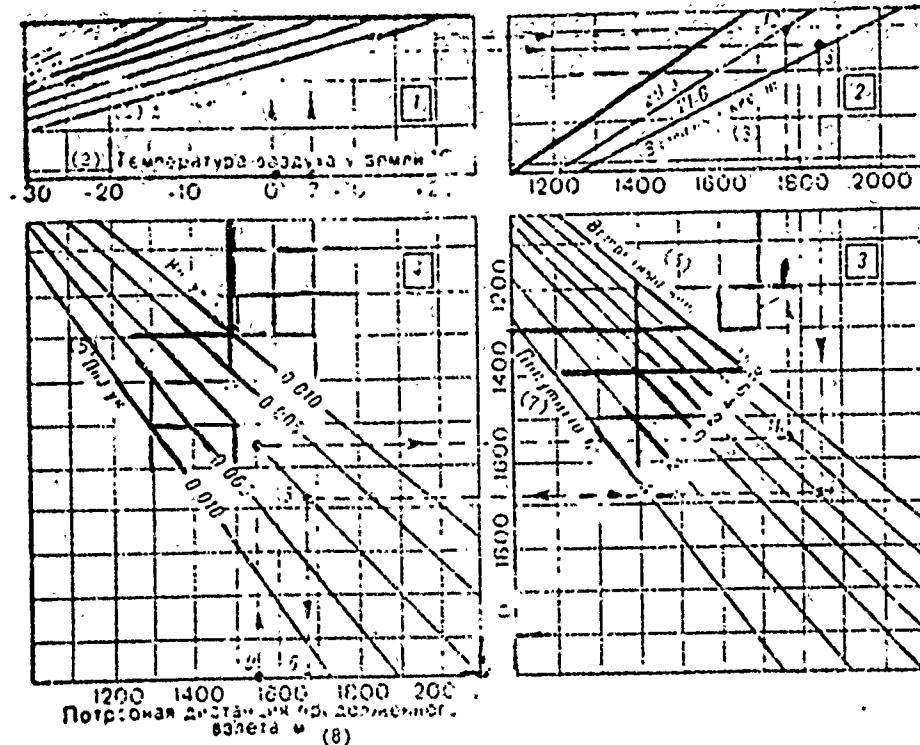


Fig. 121. Nomogram for determining the required distance for a prolonged takeoff depending on the takeoff conditions (take-off weight from 2 to 21 T).

KEY: (1) - Atmos. pressure, mm Hg; (2) - Air temperature at ground; (3) Take-off weight, T.; (4) By an angle; (5) Under an angle; (6) Head wind m/s; (7) Tail wind; (8) Required distance for prolonged takeoff.

Answer: Required distance for prolonged takeoff is equal to 1670 m (6).

2. Initial data:  $t_0 = 5^\circ\text{C}$  (7),  $p_0 = 760$  mm Hg (8), available distance for prolonged takeoff is equal to 1550 m (9), slope  $\gamma = 0$  (10), head wind  $W = 6$  m/s (11).

Answer: Take-off weight should be no more than 20.5 T (12).

The indicated nomograms are obtained during aircraft tests and are sent to the operational enterprises of civil aviation. In proportion to the changes in the characteristics of aircraft in connection with its refinement and modification in series the nomograms also undergo changes. Therefore it is not expedient to

place in a handbook all the nomograms used, especially because each crew has the capability to use them constantly in airports during preflight operations and aboard.

In addition to nomograms in civil aviation wide used is also made of all possible graphic representations. In traffic control rooms they use a movement chart based on the following principle: along the X axis at the appropriate distances, taken in a specific scale, will be plotted the intermediate points through which an aircraft flies during its movement on route. On the Y axis and on a straight line parallel to it and drawn from a point on the X axis which corresponds to KPM, also in the necessary scale the time of day is plotted (most frequently Moscow). Knowing rated speed or scheduled speed, it is possible to draw a straight line between the point which corresponds to the take-off of the aircraft from the IAM and a point which corresponds to the time of its arrival at the KPM. Dropping to this line perpendiculars from points on the X axis which correspond to check points on route, and then carrying to axis Y the obtained points of intersection of the perpendiculars with the straight line of the calculated movement, we will obtain the calculated time of flying over the KO. Obtaining from the aircraft a report about the time of actual flight over the KO, the dispatcher can always draw the line of actual aircraft movement, determine the time of its actual flight over subsequent KO's, and introduce corrections to movement as needed. On such a graphic representation it is easy to determine the rendezvous of aircraft, the catching up or overtaking of one by another, and also the time of encounter of the aircraft with darkness or dawn.

Most widely used by the crews of civil aviation are cruising charts (Fig. 122) for all types of aircraft. The schemes (keys) for the solution of problems with the help of such charts are given on them or are given in the manual of flight operations for the given type of aircraft.

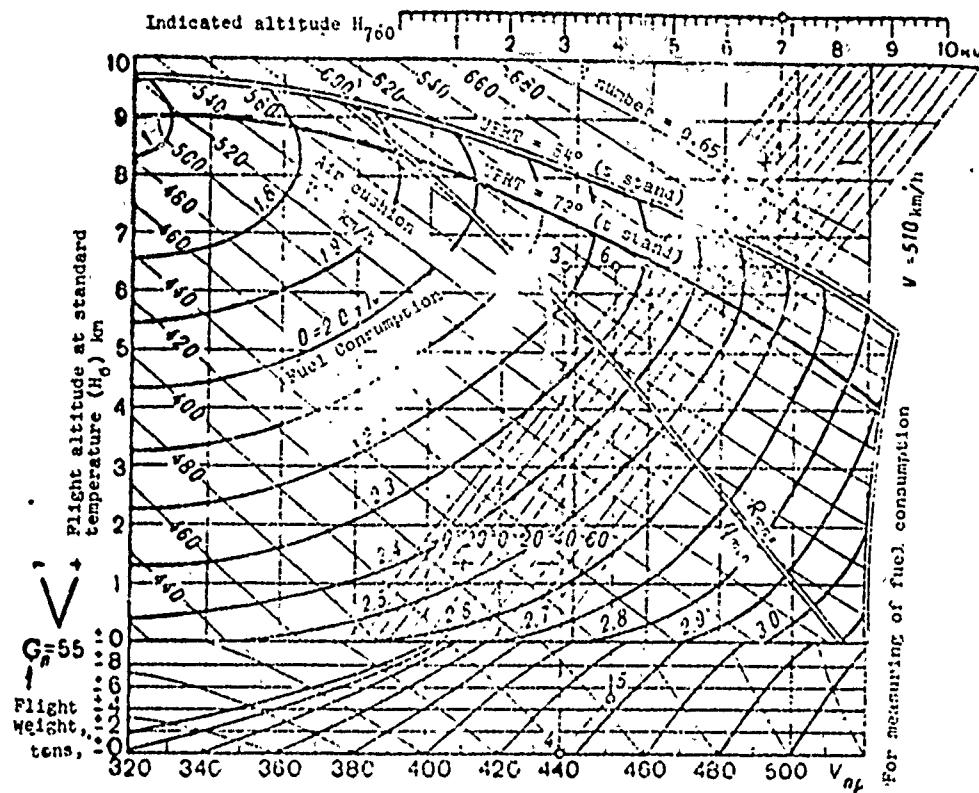


Fig. 122. Cruising chart for IL-18 aircraft with AI-20K engines.

## ABBREVIATIONS AND CONVENTIONAL SYMBOLS USED IN AIR NAVIGATION

## Points and lines

MS - aircraft position

IPM - departure point

KPM - flight point of destination  
[also can mean route check point]

I<sup>PO</sup>M = initial point of return flight

KE - control stage

KO = reference landmark

LZP = specified track

LFP = actual track

LRP = locus of equal bearings

LRA - line of equal azimuth  
ALP - astronomical line of position  
LRV - line of equal altitudes  
RNT - radio navigation point  
RVS - radio broadcasting station  
PSBN - short-range navigation radio system

#### Angles and directions

IK, MK, KK - true, magnetic, and compass courses  
IPU, MPU, PMPU - true, magnetic and landing (magnetic) track angles  
ZPU, FPU - assigned and actual course angles  
 $\Delta_m$  - magnetic declination  
 $\Delta_k$  - deviation  
 $\Delta$  - variation  
 $\Delta_p$  - radio deviation  
PK - aircraft course correction  
DP - supplement to correction (for the remaining distance)  
US - drift angle  
UV - wind angle  
KUR - radio station angle of approach  
OK - orthodromic course  
OPU - orthodromic course angle  
OMPU - orthodromic magnetic course angle  
KUR<sub>нрд</sub> - precalculated heading of RNT  
KUO - reference point angle of approach  
IPO, MPO, KPO - true, magnetic, and compass bearings of reference points  
OP - supporting meridian  
IPR, MPR - true and magnetic bearings of RNT  
IPS, MPS - true and magnetic bearings of aircraft (from reference point or RNT)  
 - reference landmark (IPM, PPM, IPOM, KPM)  
 - target



- stationary homer (KM - call sign, 425 - frequency).



- mobile homing radio station



- stationary communications radio station



- stationary and mobile radio direction finders (inside is written: K - command: B - lateral, O - without a communications radio station).



- stationary and mobile VHF radio direction finders



- stationary and mobile radio beacons



- hyperbolic radar installation



- radar detection station



- stationary radio system



- mobile radio landing system



- course or glide path radio beacon (inside it is designated by the letter K or G)



- radio marker beacon



- code neon light beacon (transmits the letters KR)

- rotating light beacon (rotation 5 rpm, operation 1 min, interruption 2 min)
- magnetic declination (with its sign)
- altitude mark of locality over sea level
- mark of excess (+) and decrease (-) in the locality of the landing airfield
- track
- line of bearing from the reference point to aircraft (time 11 h 08 min)
- line of bearing from RNT to aircraft (time 8 h 36 min)
- line of equal altitudes (astronomical line of aircraft position, time 14 h 05 min)
- calculated and actual time of passage of reference point
- numerator ( $S = 150$ ) is distance in the kilometers between reference points; denominator ( $t_n = 0.30$ ) is the flight time between reference points; magnetic course angle ( $MPU = 147$ ) for the flight between reference points
- BU - lateral deviation in degrees
- LBU - course line deviation in kilometers
- $\phi^\circ$  - latitude of station (point)
- $\lambda^\circ$  - longitude of station (point)
- $\delta^\circ$  - correction for the convergence of meridians (for the maps with a conical projection)

$\gamma^\circ$  - loxodromic correction (for maps with  
 an isogonal cylindrical projection)  
 VU - vertical angle  
 UR - angle of turn (change of course)  
 $t_{pas}$  - time of turn  
 $\beta^\circ$  - angle of a bank  
 UUR - lead angle of turn  
 R - radius of turn  
 LUR - linear lead of turn  
 $\omega$  - angular velocity of turn  
 $\delta^\circ$  - wind direction (meteorological - from  
 which it blows)  
 $\Delta_H$  - instrument correction of altitude indicator  
 $\Delta H_\delta$  - correction to barometric altitude on a  
 pressure change  
 $\Delta H_p$  - correction for terrain relief  
 $\Delta H_t$  - systematic temperature correction of  
 altitude indicator  
 X - mark of aircraft position determined by  
 flight over a reference point or over the  
 point ZOS (visually or with the help of  
 instruments) [ZOS - ground aids to  
 navigation]  
 $\Delta$  - mark of aircraft position obtained by plotting  
 and by the dead reckoning (including with  
 help of automatic plotters and calculators)  
 e - mark MS, obtained from the  
 ground by request of the crew  
  
 - normal turn  
 (left)  
 - broadcasting station with an indication of the  
 height of the tower

$MK_1$ ,  $MK_2$ , - magnetic landing patterns: first, second,  
 $MK_3$ ,  $MK_4$  etc.

Velocity, distance, and altitude

$V_u$  - true airspeed

$V_{np}$  - indicated airspeed

$W$  - ground speed

$U$  - wind velocity

$GD$  - horizontal range

$ND$  - slant range

$S$  - distance between two points in kilometers

$B$  - base (the distance between RNT)

$D$  - distance on earths surfaces from the place  
of the projection of aircraft to some point  
in km

$H_u$  - true altitude

$N_6$  - barometric altitude

$N_0$  - relative altitude (the altitude of  
aircraft relative to any level)

$N_{asc}$  - absolute altitude (the altitude of  
aircraft relative to sea level)

$N_{6/760}$  - safe altitude for a pressure of 760 mm  
Hg

$N_{6/sep}$  - safe altitude based on the pressure  
at the airfield

$N_p$  - absolute altitude of point of  
relief

$N_{sep}$  - the airfield elevation relative to  
sea level

$N_{np}$  - indicated altitude (readings of  
altimeter)

$N_{760}$  - conditional altitude (vertical separation)

### Elements of time

$T_M$  - the local (civil) time  
 $T_{GP}$  - Greenwich time  
 $T_n$  - local time  
 $T_A$  - standard time  
 $t_n$  - course time  
 $t$  - time of flight  
 $u_q$  - correction of chronometer (watch)  
 $N_q$  - number of time zone  
 $\omega$  - daily variation of watches  
 $T$  - time for measurement of astronomical altitude  
 $T_{\odot}$  - true solar time  
 $T_{\odot m}$  - mean solar time  
 $\eta$  - the equation of time  
 $S$  - sidereal time  
 $S_{GP}$  - sidereal Greenwich time  
 $S_M$  - sidereal local time  
 $D$  - correction for movement of  
aircraft

### Elements of aviation astronomy

$Z$  - zenith  
 $Z'$  - nadir  
 $\gamma$  - the vernal equinox  
 $K$  - the point of summer solstice  
 $\underline{L}$  - the autumnal equinox  
 $L$  - the winter solstice  
 $z$  - the zenith distance of a celestial body  
 $h^{\circ}$  - the astronomical altitude (measured, corrected)

$h_{\text{изм}}^o$  - astronomical altitude (measured by aircraft sextant)  
 $h_s^o$  - computational altitude (tabular)  
 $h_{\text{пол}}$  - the altitude of Polaris  
 $\Delta h$  - altitude difference of celestial body  
 $A^o$  - azimuth of celestial body, navigational  
 $\delta^o$  - declination of celestial body  
 $\alpha^o$  - right ascension of celestial body  
 $t$  - hour angle of celestial body  
 $(t_{\text{gp}} - \text{Greenwich}, t_m - \text{local})$   
 $r$  - correction for refraction of earth's atmosphere  
 $K$  - dome refraction  
 $\pm p$  - parallax  
 $-\delta$  - correction for a dip of the horizon  
 $\zeta$  - correction for sextant (instrument)  
 $\pm q$  - correction for rotation of earth  
 $E$  - correction for movement of aircraft (during the observation of Polaris it is designated  $D_n$ )  
 $\Delta \phi_{\text{пол}}$  - correction for the altitude of Polaris  
 (it is added to the altitude of Polaris when determining the latitude of a place)

#### Meteorological elements

$p_0$  - atmospheric pressure at the earth  
 $p_n$  - atmospheric pressure at altitude  
 $t_0$  - the temperature at earth  
 $t_n$  - temperature at altitude  
 $t_{\text{ср}}$  - temperature average  
 $t_{\text{ср}} = \frac{t_0 + t_n}{2}$   
 $t_{\text{град}}$  - vertical temperature gradient.

SIXTH SECTION

## INFORMATION ABOUT AIRBORNE RADARS

### BASIC INFORMATION ON RADAR

Radar is the name of the field of radio engineering which uses for the detection and position finding of airborne, above-water, and ground-based objects the phenomenon of the reflection and radiation of electromagnetic waves by these objects.

#### Radar Methods

Pulsed radiation. In such a method short-lived signals with long pauses between them are periodically sent out and then the reflected signals from the object are received during the periods between the next sending of signals (pulses). Distance to the object can be calculated from the following formula

$$d = \frac{ct}{2}$$

where  $c$  - the propagation velocity of radio waves;  $t$  - the delay time (passage of the signal from the station to the object and back).

The pulsed method is characterized by: the pulse duration  $\tau$ ; the period  $T$  or frequency  $F$  of pulse repetition; pulse energy  $W_u$ ; power in pulse  $P_u$  and by average power  $P_{cp}$ .

Distance to distant object should not be more than

$$d = \frac{cT}{2}.$$

The minimum range of detection for a radar station is

$$d_{min} = \frac{c\tau}{2}.$$

The energy being transferred by the impulse of radio waves is called pulse energy. The power being developed by a transmitter during the pulse duration is called pulse power  $P_u$ . The power in a pulse is connected with pulse energy by the relationship

$$P_u = \frac{W_u}{\tau}.$$

The average power of a transmitter is the power which it would develop while working continuously and maintaining the same energy of radio waves

$$P_{cp} = W_u F = P_u \tau F = P_u \frac{\tau}{T}.$$

Continuous radiation consists of the fact that the transmitter and receiver work in frequency, whereupon the degree of distinction depends on the distance to the object. For a decrease in the influence of transmitter on receiver in similar stations two antennas are used one for transmission, the other for receiving.

The Doppler effect amounts to the fact that in the case of movement of a transmitter relative to a receiver or the receiver relative to a fixed transmitter the frequency of vibrations being received by the receiver does not coincide with the frequency of the radiated radio waves.

The difference frequency

$$f = f_{\text{obj}} - f_{\text{imp}} = \pm f_{\text{imp}} \frac{2v_r}{\lambda_{\text{imp}}},$$

where  $v_r$  - the radial velocity of an object in the direction toward the radar station.

If we express  $v_r$  in kilometers an hour, and the wavelength  $\lambda$  in centimeters, then

$$f = \pm 55.6 \frac{v_r}{\lambda} \text{ Hz.}$$

In general the difference frequency

$$f = \pm 55.6 \frac{v}{\lambda} \cos \alpha,$$

where  $v$  - the velocity of the object;  $\alpha$  - the angle between the velocity vector of the object and the direction to the radar station.

By means of measurement of  $f$  it is possible to determine  $v_r$  of the discovered object. With the help of this method it is possible to find only moving objects, but it is not possible to determine the object distance and the quantity of other smaller objects found in it.

This principle is used in aircraft radio navigation stations for determining the ground speed of an aircraft and drift angle.

The formula for determining the ground speed of an aircraft from Doppler frequency takes the form:

$$v = \frac{F_0 \lambda}{2 \cos \beta}.$$

where  $\beta$  - the angle between the direction of the vector of ground speed of the aircraft and the direction of the axis of the beam of the station.

The drift angle (US) is determined by rotation of an antenna device in a horizontal plane relative to the vertical axis at constant angle between the left and right beams, attaining an equality of frequencies of reflected signals.

#### DETERMINING THE POSITION OF AN AIRCRAFT AND NAVIGATIONAL ELEMENTS WITH THE HELP OF AIRBORNE RADARS

Airborne radars make it possible to solve all problems of air navigation.

It is most convenient to identify landmarks at scales of operation of radars which are close to the scales of flight maps. For example at a screen radius of 55 mm an image scale of 1:1,000,000 is obtained at a range scale of 55 km in the radius of the screen.

When using maps with a scale of 1:2,000,000 it is most convenient to use a radar scale of 110 km, if it has been provided for by the construction of radar, if it has not been provided for, then use a scale of 100 km.

With the help of the selection of contrast by the separate strengthening of signals of high and low levels, by the selection of the slope angle of the antenna and luminance of the scanning beam the clearest isolation of radar reference points on the screen of radar is attained.

The position of the aircraft (MS) is determined with the help of a circular scan radar with a rotating bearing scale by plotting on a map the bearing and distance from the reference point to the aircraft taking into account the correction for the convergence of meridians, if the difference in longitudes of the reference point and MS is considerable.

If onboard there is a circular scan radar then the bearing of aircraft is obtained as a result of the summation of the heading of the reference point and the course of the aircraft.

Since radar measures not the horizontal, but slant range, at distances to the reference points less than fivefold the flight altitude the correction  $\Delta R$  should be introduced into the measurements. This correction always has a negative sign. For the introduction of these corrections it is recommended to use Table 30.

Table 30. Correction for the slant range ( $-\Delta R$ ).

(1) Slant range, km, $\Delta R$	Bearing angles, deg											
	1	2	3	4	5	6	7	8	9	10	11	12
5	0	0,5	1	2	5	—	—	—	—	—	—	—
10	0	0	0,5	1	1,5	2	3	4	6	10	—	—
15	0	0	0	0,5	1	1,5	2	2,5	3	4	5	6
20	0	0	0	0	0,5	1	1,5	2	2,5	3	3,5	4
25	0	0	0	0	0	0,5	1	1,5	2	2,5	3	3,5
30	0	0	0	0	0	0	0,5	1	1,5	2	2,5	3
35	0	0	0	0	0	0	0	0,5	1	1,5	2	2,5
40	0	0	0	0	0	0	0	0	0	0,5	1	1,5
45	0	0	0	0	0	0	0	0	0	0	0,5	1
50	0	0	0	0	0	0	0	0	0	0	0	0

KEY: (1) Slant range, km; (2) Flight altitude, km.

When the slant range is equal to the flight altitude, then the horizontal range is equal to zero. This is explained by the appearance in the center of the radar screen of a dark spot with a sharply designated border, the distance of which from the center of the screen is equal to the actual flight altitude over the particular locality. Therefore this spot is called altimetric.

Airborne radar can serve directly for determining orthodromic MS coordinates. For this purpose the bearing scale of the indicator should be set on the lead angle (UU) of the aircraft relative to its assigned orthodromic track angle (FU) (Fig. 123).

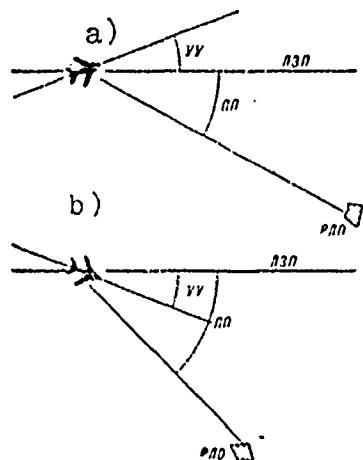


Fig. 123. The determination and calculation of the track bearing of the reference point: a) with a positive US; b) with a negative US.

Examples. 1. If drift is positive and  $UU = -15^\circ$ , the bearing scale is set with the division  $345^\circ$  opposite the course line. Then in the case of a heading of  $35^\circ$  for the reference point its track bearing (PP) will be equal to  $20^\circ$ .

2. If drift is negative,  $UU = +8^\circ$  and the heading of the reference point is equal, for example, to  $17^\circ$ , then the division of  $8^\circ$  on the bearing scale of indicator is set opposite the course line. Then the PP of the reference point will be equal to  $25^\circ$ .

Knowing the orthodromic coordinates of a reference point relative to the intermediate point of the route (PPM), and also the track bearing and the distance from the aircraft to the reference point, on the NL-10 rule it is possible to calculate the orthodromic coordinates of the aircraft relative to the last PPM. For this the triangular index of scale 4 (Fig. 124) is combined with the distance of the reference point from the aircraft  $R$  on scale 5. The aiming hair is combined on scale 3 with the value  $90^\circ - \text{PP}$  and on scale 5 the value  $R \sin (90^\circ - \text{PP})$  is read; then the hair is combined with the value  $\text{PP}$ , reading on scale 5 the value  $R \sin \text{PP}$ . After this the first value obtained is subtracted from the coordinate of the reference point  $x_{\text{op}}$ , and the second - from  $z_{\text{op}}$  and the  $x$  and  $z$  of the aircraft are obtained.

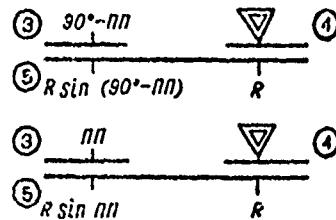


Fig. 124.

This same problem, but considerable simpler and with a greater deal of accuracy, is solved during flight over the beam of a reference point, i.e., when  $\text{PP} = 90^\circ$ . In this case  $x_{\text{MS}} = x_{\text{op}}$ , and  $z_{\text{MS}} = z_{\text{op}} - R$ .

Such a particular case of the solution of the problem is rarely encountered when using a sector scan radar.

When using a sector scan radar for determining the orthodromic coordinates of an aircraft the track bearing of the

reference point is calculated according to formula  $PP = KUO + UU$  and the problem is solved just as for a circular scan radar. In this case it is recommended to sight the reference points with the largest possible headings.

The ground speed and drift angle of aircraft can be determined most simply by successive MS, but this method is frequently insufficiently operative for determination of the US, since it requires a considerable base for measurements.

It is possible to use several different methods if in the field of view there are unidentified sighting points which do not make it possible to determine the MS.

Sighting of a point near the course line. If a sighting point which is very noticeable on the radar screen is transferred near the course line, then W and US can be measured by sighting the run of this point. It is recommended to make such a sighting within the limits of a distance from 60 to 30 km in order to avoid altitude errors.

At the moment of intersection by the point of the 60 km range mark the time is noted and the bearing scale by point "0" is set opposite the course line, and the line of sight - parallel to the movement of the point. When point intersects the 30 km range mark they again note the time and count off the time of flight of the base whereupon on the NL-10 W is determined while adding to the length of the base the correction for the flight altitude for a distance of 30 km. The drift angles are reckoned according to the bearing scale whereupon negative angles are taken as a supplement up to  $360^\circ$ .

This method is sufficiently precise for the measurement of drift angle. Ground speed due to a too short of a base of

measurements is determined with large errors. For example at a flight speed of 900 km/h the error in the flight time of a base of 4 s gives an error in measurement of  $W$  up to 30 km/h.

**The method of a right triangle.** This method is more precise and convenient than sighting the point near the course line and presents greater possibilities for the selection of reference points for sighting.

Having set the zero on the bearing scale opposite the course line and having measured with the help of the sight the heading of the reference point, and based on the circular marks - its range, it is necessary to turn on the stop watch. After this, without changing the position of the sighting device, it is necessary to follow the movement of the reference point on the screen up to intersection of this reference point with the perpendicular line of the sight. At this moment the stop watch is stopped and again the range of the reference point is determined based on the circumferential marks (Fig. 125). After this, having introduced into both measured slant ranges the corrections for flight altitude from a table, the NL-10 is used to calculate the angle  $\alpha$  between the position of the sighting line and the direction of movement of the reference point (key see in Fig. 126a), and also the length of the base of measurement  $S$  (key see in Fig. 126b);  $\alpha$  and  $S$  can also be calculated from the formulas:

$$\operatorname{tg} \alpha = \frac{R_2}{R_1}; \quad S = \frac{R_1}{\sin(90^\circ - \alpha)}.$$

In this case the drift angle is defined as the difference between the first heading of the reference point and angle  $\alpha$

$$\text{YC} = \text{KYO}_1 - \alpha,$$

and the ground speed as the relationship of the base length to the time of its flight

$$W = \frac{S}{t}$$

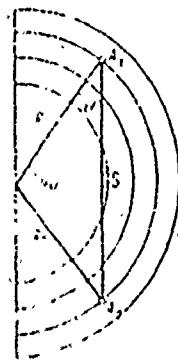


Fig. 125. Determining of navigational elements by the method of a right triangle.

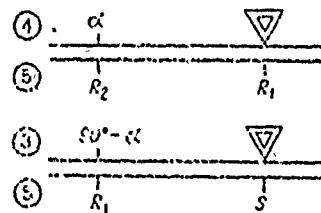


Fig. 126.

The twofold direction finding of sighting point at equal slant ranges. This method is most precise when determining US and W by the method of sighting, but requires greater expenditures of time than the previous one.

In the case of passage by a readily noticeable sighting point of some circumferential range mark in the forward section of the screen the timer is turned on and the heading of this point is measured (Fig. 127).

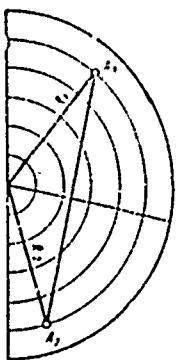


Fig. 127. The twofold direction finding of sighting point at equal slant ranges.

At the moment of the secondary intersection of this sighting point with the same range ring in the rear end of the field of view the timer is turned off and for the second time the heading of the sighting point is determined.

It is evident that if  $R_1 = R_2$ , then the line of movement of the sighting point from  $A_1$  to  $A_2$  is perpendicular to the bisector of the angle between  $R_1$  and  $R_2$  and this means that with the passage of the sighting point more to the right of the course line of the aircraft

$$y_C = \frac{KYO_1 + KYO_2}{2} - 90^\circ;$$

in the case of passage of the same sighting point to the left of the course line

$$y_C = \frac{KYO_1 + KYO_2}{2} - 270^\circ.$$

where  $KYO$  - reference point angle of approach.

After introduction into the slant range of the correction for flight altitude the length of the base of measurement is determined according to the formula

$$S = 2R \sin \frac{KYO_2 - KYO_1}{2}$$

(key see Fig. 128a), and ground speed  $W$  - by the usual method on the NL-10 (key see in Fig. 128b).

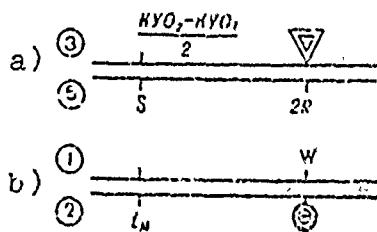


Fig. 128.

Determination of US based on the secondary Doppler effect by the method of "stopped antenna." In the case of a certain experience in the selection of strengthening of the receiver and slope angle of antenna the US can be measured by this method in several seconds, especially as some airborne sector scan radars have for this purpose a special mode and supplementary indication. The essence of this method lies in the fact that during the circular rotation of the antenna the pulsations of frequencies are not noticeable to the eye, since every flowing point is passed rapidly by the scan beam and is depicted on the screen as an individual flash with subsequent afterglow. The weak visual impression from the secondary Doppler effect remains also with a fixed radar antenna in the case of considerable noncoincidence of the direction of its radiation with the direction of movement of the aircraft. In this case the scintillation of points occurs with a high frequency and it is smoothed out by the screen afterglow. But if the direction of the antenna is slow to approach the direction of movement of the aircraft, then the glowing points begin to flash with increasingly less frequency and with increasing amplitude.

In this way the most gradual, but the brightest flashing of the glowing points on the screen indicates the agreement of the antenna bearing with the direction of movement of the aircraft.

The drift angle is defined as the angle between the position of the sweep trace on screen in the case of maximum secondary Doppler effect and the course line.

Note. When determining the US by any of four methods examined here the bearing scale can be set not on zero, but on the aircraft course. In this case in all the calculations the KUO is replaced by the bearings of the reference points and as a result of the solution the US is not obtained, but the actual course angle (FPU) of the aircraft (for example, the orthodromic FPU of the aircraft, if the bearing scale is set on the orthodromic course of the aircraft).

#### POSSIBLE BREAKDOWNS IN THE OPERATING CONDITIONS OF THE RBP-4 AND METHODS FOR THEIR ELIMINATION IN FLIGHT

Disruption of the AFC in rear sector. In operation fairly often disruption of the AFC is observed in the rear sector ( $170-180^\circ$ ) with the formation of blackout. In this case the current of the crystal "Osn." in the case of passage of the rear sector by the antenna falls on zero. This phenomenon is connected with the intense reflection of antenna radiation from the rear wall of the hatch. With the emergence of the indicated defect it is necessary to increase the slant of the antenna, which decreases the intensity of irradiation by reflected beams.

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[Translators Note: АПЧ = AFC = automatic frequency control; Осн. = Osn.]

Periodic disruption of the AFC. In the case of erratic operation of the AFC it is necessary to be guided by the following:

check the voltage level of the AFC and ascertain that the voltage is within normal limits;

check the presence of symmetric drops in the currents of crystals and if necessary attain their symmetricalness with the potentiometer "Napr. AFC" [Напр. АПЧ].

If the operation of the AFC is not restored it is necessary to switch to manual adjustment, for which the rotation of the antenna is turned off and adjustment is conducted on the maximum image brightness on the 100 km scale.

During operation of the radar on manual adjustment the switch key "Control" [Контроль] should remain in that position in which adjustment was carried out. Its changeover requires supplementary tuning.

Frequent switching off of the transmitter usually occurs as a result of interelectrode breakdowns in the radio tube of the GMI modulator, failure of the magnetrons, and a change in the charging in the transmitter. In the case of frequent switching off of the transmitter it is necessary to switch to the 10-70 scale (with a smaller pulse duration).

It must be borne in mind that switching off of the transmitter is observed in the case of insufficient warming up. Warming up of the set before switching on the transmitter should take 5-7 min in the summer and no less than 15 min in the winter.

The spontaneous misphasing of scan is exhibited outwardly in the jamming of scan in the lower sector. In this case it is necessary to turn off the circular rotation of the antenna, and, rotating the antenna in the search mode to both sides to 360°, achieve its smooth rotation.

Sector scanning. The phenomenon of sector scanning consists of an alternation in the luminance of scanning, as a result of which during rotation its screen is covered by fan-shaped sectors. Sector scanning can occur for the following reasons:

defects in the circuits for forming the scan;

defects in circuits for strengthening the scan;

misphasing of the selsyn system.

In the emergence of sectoring it is necessary to be certain which of these three causes caused the sectoring.

In the case of unstable phasing sectoring usually occurs in the rear sector, and the course line is displaced. In this case it is necessary to phase the selsyn system. If sectoring is caused by the other reasons, it is necessary to completely withdraw the knob "Amplification of receiver" opposite the hour hand.

When sectoring is caused by the abnormal operation of amplification circuits, then it disappears; if the cause is in the defects of the scan-forming circuit, then sectoring will continue.

Table 31. Characteristic signs of the failure of fuses (in the table the fuses are arranged in the same order as in the regulating box).

Protected unit	Voltage of circuit, V	Rating of fuse, A	No. of fuse in R15	Outward signs
Range unit	115	2	Pr15-1	Scan absent. In the center of the screen a glowing point.
Synchronizer	115	2	Pr15-2	Scan absent. No luminous spots in the center of screen. No illumination of indicator scale
Indicator	115	5	Pr15-3	Scan rotates with jamming in the rear sector
Regulated rectifier	115	5	Pr15-4	Scan absent. Glowing spot in the center of screen, but it is not controlled in brightness, there are no currents and +300 and -300 V voltages
High-voltage rectifier	115	2	Pr15-5	Scan absent. No luminous spots in center. Illumination of indicator works
Not working	-	-	Pr15-6	-
Transmitter and modulator	115	10	Pr15-7	No image of terrain. No currents for crystals and magnetron
Antenna	115	5	Pr15-8	Scan rotates with jamming in the rear sector and is not phased
Control of range unit and panel	27	15	Pr15-9	Scale marks knocked off. During the rotation of the delay potentiometer for altitude the marks do not go into the center of the screen, but from the center
Not working	-	-	Pr15-10	-
Transmitter-receiver and modulator	27	15	Pr15-11	Are no currents of crystals and magnetron. When starting the transmitter on scan there is no sounding pulse
Antenna and indicator	27	10	Pr15-12	Scan does not rotate. The indicator of inclination goes off scale upward
Azimuth 1	27	1	Pr15-13	No sector fluctuation
Azimuth 2	27	1	Pr15-14	No sector fluctuation

The basic causes in the latter case are:

faulty contact in the high-voltage sucking disk on the tube;

faulty contact in the high-voltage connector of the high-voltage amplifier;

erratic operation of the system for amplification of scanning.

With faulty contact in the sucking disk the contrast sectors are observed on the screen and their flare angle is changed with a change in the luminance of scan.

The same is observed with faulty contact in the connector of the high-voltage amplifier.

When defect is detected it is necessary to turn off set, free the wing nut securing the forward section of the housing, and carefully remove it without damaging the wire for illumination of the indicator. After this the suction disk is set by pressure on it. With the correct installation of the suction disk a distinct click will be audible. If the suction disk has been installed correctly, and sectioning continues, it is necessary to check the reliability of connection of the high-voltage rectifier.

In the case of erratic operation of the scan amplification system it is necessary to interchange the position of tube 6P3 in the synchronizer.

Sectoring because of the abnormal operation of the signal amplification circuits is difficult to eliminate in the air.

This sectoring will be less, the less the potentiometer "amplification of receiver" is put in.

In the case of inoperation of stations due to the breakdown of fuses it is necessary to be guided by Table 31.

In the case of burning out of the general 115 V fuse in the fuse board of navigator the voltmeter on the control panel will not show a voltage of 115 V.

#### The Order of Replacement of Radio Tubes in the Units of a Radar Set

During the replacement of radio tubes in units it is necessary to be guided by the following:

replace radio tubes only after testing the soundness of fuses;

based on the nature of defect determine in which unit it is not necessary to replace the radio tube;

unscrew the locks securing the unit; pull out the unit and open the upper lid;

based on the brightness of the incandescent filaments of glass radio tubes ascertain that the incandescent filaments are whole; be convinced by touch that metallic radio tubes are warm;

check the reliability of installation of radio tubes in the tube panels;

Table 32. Some possible failures of radio tubes.

Manifestation of failure	In which unit	Radio tube undergoing replacement
Scan disappeared. Glowing point present. Upon switching on the stepped delay the scan appears	Range unit	Radio tube L3-4 for altitude delay
marks on all scales disappeared. On scale 10 the marks are knocked off. Currents of magnetron - 0. Image made worse, there are no 2-kilometer marks	The same	Radio tube 13-2 for divider 5:1 Radio tube L3-1 for generator of 3-kilometer pulses
Image disappeared. Marks on all scales. Current of magnetron - 0	"	Radio tube L3-5 for trigger amplifier
Scan and mark normal, but no image. Current of magnetron - 0. Upon the introduction of stepped delay the magnetron current appears, and the scan disappears	"	Radio tube L3-2 pcs. (L3-8 and L3-9) for generator of 16-kilometer pulses and coincidence amplifier
Scan disappeared. Glow point present.	"	Radio tube L3-3 for divider of starting pulse
Scan disappeared, glow point present. All points, including the magnetron current, normal	Synchro- nizer	Consecutively replace tubes: L4-21 of buffer amplifier; L4-22 - sweep oscillator; L4-23 - sweep amplifier; L4-24 - sweep amplifier; L4-25 - end amplifier; this tube can be interchanged with adjacent tubes 6P3
Scan and marks disappeared. Scan disturbed	The same	L4-19 limiting of scan
Scan shortened to 1/3 the radius of tube	"	L4-20 of multivibrator for starting of scan
Scan and mark normal, all points normal, but image disappeared	"	L4-9 of input amplifiers
AFC does not work in position "AFC on." AFC voltage "not sawtooth," AFC voltage decreased. In the position of AFC turned on and turned off, receiver is adjusted by knob "Adjustment of receiver" scan only on periphery of tube.	"	Tube for generator of sawtooth oscillations
Scan -300 v voltage	Regula- ted rec- tifier	L11-5
marks and picture diffuse, +300 v off scale	The same	L11-11
voltage +300 v understated by 20-30 v	"	L11-4

when replacing a radio tube it is necessary to take it out of the panel carefully and to insert the new tube, having ascertained preliminarily that the key of tube fell into the slot.

In the case of failures of radio tubes it is necessary to be guided by Table 32.

POSSIBLE FAILURES OF THE RPSN-2 [EMBLEM]  
RADAR SET AND METHODS FOR THEIR  
ELIMINATION IN FLIGHT

Set not connected. Power not supplied to set. Upon connection of the disc-type switch key "Control" into the position " $\sim 115$  V" on the control and regulating panel the dial instrument does not show  $\sim 115$  V.

It is necessary to check the connection of the following switches:

on the panel of the circuit breaker the switch keys "Power for "Emblem" set" and "Control of "Emblem" set," should be set in the "On" position;

the switch "ground-based power supply for "Emblem" - power supply of "Emblem" from SGO-8," located on the radio operator's panel, should be set in the position "power supply of "Emblem" from SGO-8";

switch "On-Set-High" on the control and regulating panel set in the position "Set" (mid-position).

If with the setting of the switches in the indicated positions the set is not turned on it is necessary to check the conditions

of the fuse for the ~115 V circuit on the radio operator's panel and the 10A fuse in unit No. 9.

**Failure of the AFC system.** During operation of the set in the mode "Scanning" strong sectoring on the indicators appears and in the dark places of sectors signals are absent. With the setting of the "Control" switch in the position "Current of crystal 1F amplifier" and "Current of crystal AFC" fluctuations of the instrument pointer appear.

For elimination of the indicated defect it is necessary that the "AFC-MFC" switch located on the control and regulating panel be set in the position "MFC." Slowly rotating the "MFC" potentiometer, which is located over the "AFC-MFC" switch strive for a peak signal of luminance from the earth's surface on the indicators for the pilot and navigator. In this case the set should operate in the condition "Scanning" or "Aircraft" and the antenna should be tilted down by 6-8°. [AP4-PP4 = AFC-MFC, automatic frequency control-manual frequency control].

The "MFC" system should be adjusted after a 20-minute warm-up of the set. After adjustment do not rotate the "MFC" potentiometer.

It is necessary to remember that the optimum signal from the earth's surface can be obtained in two positions of the "MFC" potentiometer. These two positions will correspond to the two different values of crystal current.

It is necessary to select the position of the "MFC" potentiometer which corresponds to the greater value of crystal current, equal to 0.4-1 mA (4-10 divisions on the scale).

Scan absent on indicators. In this case it is necessary to check the fuses on the fuse and adjustment panel - unit No. 9 to the right of the pilot and on unit No. 5. If fuses are blown replace them. If the fuses are operable, then check the presence of scanning on the other scales. If there is a scan on another scale then it is necessary to work with this scale.

Deviation in the value of the magnetron current from the norm 14-21 mA. For the elimination of this it is necessary with the voltage regulator of the second engine, located on the radio operator's panel, to change the voltage level  $\sim 115$  V within the limits of  $\pm 4\%$ , in order that with a change in voltage  $\sim 115$  V to set the magnetron current within the required limits.

Note: It is necessary to remember that in the conditions "Drift" and "Drift accurately" and at a scale of "50 km" during control from the navigator the magnetron current can be different from the value of current during operation of the set in the other modes.

Gyrostabilization system does not work. On the navigator or pilot's indicator periodic illumination of the left and right edge of the indicator appears. It is necessary to be convinced of the soundness of the 36 V and 400 Hz frequency fuses on the radio operator's panel. Replace inoperative fuses.

In the case of nonoperating gyrostabilization switch to the operation of radar without gyrostabilization. On the RPSN-2 control panel the switch is set in the position "gyrostabilization off" and in the case of bypassing thunderstorms in climb and descent make platforms for the survey of the sphere.

Absence of one of the rectified voltages in the case of measurement by the dial instrument on unit No. 10. It is necessary to be convinced of the soundness of fuses in unit No. 8. Replace inoperative fuses.

On the screen of the navigator's indicator the sweep length of one of the scales is considerably decreased. The potentiometers "displacement of X" and "displacement of Y" on the CW unit are maladjusted. Adjust the length of the scan lines on the navigator's potentiometers "displacement of X" and "displacement of Y" with the help of a screwdriver.

There is no magnetron current and a scale marks of set synchronization. Fuses blown out in unit No. 3. Check and replace fuses in unit No. 3.

Note. Replace fuses only 1 time (in all units and by the appropriate ratings); in the case of repeated blowing out" it is necessary to turn off the radar set.

#### THE AIRBORNE RADAR "GROZA"

The radar set "Groza" serves for a survey of the terrain in front of the aircraft for the purpose of navigational orientation. The radar image on the indicator is close to the image of the terrain on a map of the appropriate scale.

The bearing sector of survey of the "Groza" radar is  $\pm 100^\circ$  on both sides from the longitudinal axis of the aircraft. The division of the azimuthal indicator scale is realized every  $10^\circ$  with numbering every  $20^\circ$ . A supplementary graduation every  $2^\circ$  for measurement of drift angle is given in the sector  $\pm 20^\circ$  from the longitudinal axis of the aircraft.

The "Groza" radar, besides the assembly with one transmitter-receiver and one indicator, exists in other assemblies:

with one transmitter-receiver and two indicators;

with two transmitter-receivers and one indicator;

with two transmitter-receivers and two indicators.

The controls are located on the face panel of the main indicator (Fig. 129):

1. The on-off keys of the radar. The radar begins to operate normally in 3-5 min after switching on when its units and elements are sufficiently warmed up. This delay takes place even in the case of a temporary disconnection of the radar.

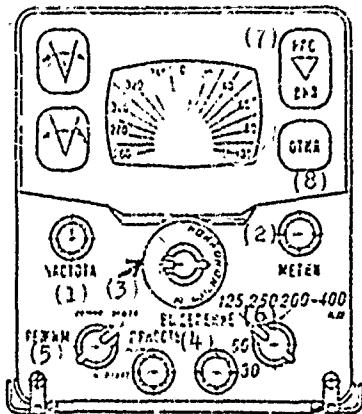


Fig. 129. The face panel of the main indicator of the "Groza".

KEY: (1) Frequency; (2) Marks  
(3) Antenna scale; (4) Brightness;  
(5) Mode; (6) Isolation; (7) Radar  
on; (8) Cut off.

2. The switch key for operating conditions marked by the label "mode" has the positions: "Ready," "Earth," "Thunderstorm," "Iso-Echo."

With the setting of the switch key in the "Ready" position, if 3-5 min prior to this the power supply of the locator was turned on, it is found in a state of readiness for immediate operation, although the radiation of the radar is absent.

With the setting of the switch in the "Earth" position the radiation of the locator is turned on and in the antenna the fan beam which is necessary for surveying the Earth's surface is formed. In this position the possibility is ensured for increasing the contrast of the marks from the necessary ground-based objects (cities, rivers, basins, against the general background of the earth's surface. This is accomplished with the regulator "isolation."

In the position "thunderstorm" a narrow beam is formed in the antenna and there is a changeover in the indicator which ensures the obtaining of the radar image of thunderstorms without interference from the earth at flight altitudes greater than 1000 m and with a luminance independent of the distance to the thunderstorms. In this mode it is possible to evaluate, from the viewpoint of safety, the magnitude of excess over the peaks.

In the position "Iso-Echo" the beam remains narrow, but because of changeovers in the indicator there is a subtraction of signals which exceed the assigned value in amplitude. This makes it possible based on the width of the darkened sections inside thunderstorm exposures to determine on indicator the probable turbulence.

In the position "Drift" the beam of the locator is fan-shaped, but the automatic azimuthal antenna rocking is switched off. All the necessary movements of the antenna beam in azimuth

are accomplished by means of pressure on one of the keys located on the left of the indicator, whereupon the rate of movement of the antenna beam of the locator can be changed with the help of the regulator "Isolation."

3. The band switch for scanning is marked "Km" and has five positions: "30," "50," "125," "250," and "400." With this switch key the scale of the radar image on the indicator is changed.

In the first four positions the scanning for range is begun at the moment of radiation of the radar and terminates at the moment of arrival of the radar from the ranges indicated on these positions. In the fifth position scanning is begun at the moment of the arrival of reflections from a distance of 200 km from the aircraft and terminates upon their arrival from a distance of 400 km.

An increase in the observation range of ground echoes and ground-based objects while preserving the continuity of image for scanning at 250 km in the mode "Earth" is achieved by the automatic deformation of the antenna beam into fan during movement of the reflector from the left to right and narrow during movement from right to left.

At the scanning range "400" in the mode "Earth" scanning is accomplished by a narrow beam, automatically oriented in a vertical plane in such a way that it overlaps the entire range of distances being scanned on the indicator. By this an increase is achieved in the detection range of cities and especially large industrial and administrative centers.

4. The slant control marked by the label "Slant" makes it possible to slant the antenna beam relative to the plane of the horizon in a range of angles  $\pm 10^\circ$ .

5. The brightness control marked by the label "Brightness" is designed in such a way that a change in brightness does not require the simultaneous brightness control of the range rings or the position change of the knob "Isolation." All the necessary corrections are introduced automatically.

6. The brightness control of "Marks" is used for changing the brightness of marks relative to the radar image.

7. The regulator "Isolation" during operation in the mode "Earth" ensures an increase in the image contrast of the objects which most interest the observer. An increase in contrast is attained by means of the elimination of the images of small ground-based objects which do not yield to or are difficult to identify from the general radar image.

In the mode "Drift" this regulator is used to change the rate of azimuthal movement of the antenna. An increase in contrast in the given mode, if in it there is no necessity, is automatically eliminated.

8. The regulator "Frequency" serves for a frequency shift in the local oscillator of the radar set and ensures the manual frequency control in the case of failure of automatic regulation, and also if necessary for the input of heterodyne frequency into the zone of the capture of the system of automation after turning on of the radar.

9. The keys for manual control of the azimuthal movement of the antenna are intended for the measurement of drift angle. They are arranged on the left of the main indicator symmetrically to the keys for the turning on and off of the radar and are marked by special marks.

The assembly with two indicators. With installation on the aircraft of a radar with two indicators all the control of the

operation of the set, and also the selection of the optimum sweep length are accomplished from the main indicator.

For the individual control of radar image on the supplementary indicator there are three regulators: "Brightness," "Isolation," and "Marks."

The assembly with two transmitter-receivers. A supplemental transmitter-receiver, if the radar has one, can be immediately put into operation by means of change-over of the toggle switch "transmitter" "thunderstorm" into the position "Reserve." This is done in the case of malfunction of the main transmitter-receiver. The supplemental transmitter-receiver plays the part not only as a hot reserve, but is used during the operation of radar on scan at 400 km, somewhat increasing the detection range of objects. In this case its connection occurs automatically.

With any of the assemblies of the "Groza" radar on an aircraft the switch key "Reserve-Stab," can be installed additionally. With its setting in the overhead position it switches off the stabilization system of the antenna from the aircraft gyro horizon when it goes out of order. This switch key is installed most frequently on the pilots' control panel in the area of the arrangement of the bank and pitch indicator of the aircraft.

Turning on the radar in flight. Before turning on the radar the controls on the main and supplementary indicators should be in the following positions:

the switch key "Mode" of the main indicator - in the "Ready" position;

the "Frequency" regulator of the main indicator - in the end position clockwise;

the "Brightness" regulator of the indicators - in the mid-position;

the "Slant" regulator of the main indicator - in the zero position;

the "Isolation" regulator of both indicators - in the end position counter clockwise;

the "Marks" regulator of both indicators - in the mid-position;

the switch key for the scanning length of the main indicator - in the position "50" or "125"

With the radar assembly with two transmitter-receivers the switch key "Transmitter "Groza," located in the crews cabin, should always be located in the down position.

For turning on the radar it is necessary to press to the detent the key "radar On" on the right from the main indicator, having preliminarily turned on the circuit breaker. The units of the locator, having warmed up, will be turned on automatically in 3-5 min.

In 3-5 min after pressing the keys it is necessary to set the necessary "modes," whereupon on the screen of the locator the range rings should be lit up. If in this case even one of the indicators of the range ring does not appear, it is necessary to rotate the "Brightness" regulators of the appropriate indicators to a position in which the rings will appear. In case it is not possible to obtain the range rings by rotation of the "Brightness" regulators, this is accomplished by the regulators "Marks" with the setting of the "Brightness" regulators in the mid-position, and also by setting the switch key of sweep length of the main indicator in the position "400" and vice versa.

The absence of rings at all accepted measures only on one of the two indicators attests to the breakdown only of this indicator while the efficiency of the entire radar as a whole is maintained.

Further after the appearance of rings it is necessary to be certain of the normal operation of the locator, for which by rotation of the regulator "Slant" counter clockwise (antenna slanted down) an angle is set equal to  $7^{\circ}$ , and the scanning range equal to "30" - in flight at altitudes of 1,000-3,000 m. During flights at altitudes 3,000-5,000 m, 5,000-12,000 m, and higher than 12,000 m ranges "50," "125," and "250" respectively are set.

In case of necessity by rotation of the "Frequency" knob counter clockwise it is possible to gain the appearance of an image of the earth's surface on the indicator.

If after rotation of the "Frequency" regulator counter clockwise up to the detent the image does not appear, adjust the "mode" switch again from the position "Earth" to the position "Ready" and again set the necessary operating conditions, having set the "Frequency" regulator into the original position. Repeat the operations described above and after the appearance of an image unless it is necessary do not touch the "Frequency" regulator. With sufficient operating experience on the locator it is possible for the return of the "Frequency" regulator to the extreme clockwise position not to transfer the "Mode" switch into the "Ready" position and vice versa, but to simply rotate the "Frequency" regulator with a sharp jerk.

If with the help of the described operations it is not possible to obtain a radar image it is necessary to increase the angle of slant of the antenna to  $8-9^{\circ}$  and to repeat the check.

During flights over a calm sea at altitudes of 5,000 m and higher the obtaining of an image on the indicator may not be possible, which does not always indicate the disrepair of the radar.

Turning on the radar on the ground prior to takeoff. After starting the aircraft engines the radar should be turned on with the help of the "Radar On" key as this was described earlier. The

"mode" handle should be moved from the "Ready" position to the "Earth" position only in the absence in an azimuthal sector with a magnitude of 100° on both sides from the longitudinal axis of the aircraft at distances less than 100 m of any large reflecting objects (hangars, large structures, etc.). Otherwise the radar can be put out of order.

With the approach of the aircraft toward the end of RW directly before lift-off the switch key "Mode" should be transferred to the position "Earth," the switch key for scanning duration - into position "30," and by rotation of the "Frequency" regulator if necessary the image of large objects in the area of the airport should be obtained. The inclination of the antenna is zero.

After this it is possible to begin the inspection of cloud formations in the area of the proposed trajectory of climb, for which the antenna is raised upward to an angle equal to the angle of climb, and the switch key for mode is transferred to the position "Thunderstorm."

Switching off the radar. During normal operation of the radar, in the case of the absence of a need for it, but with a desire to preserve its readiness for operation at any moment, it is necessary to turn off the transmitter receiver, having set the mode switch in the "Ready" position. As soon as it is required to use the radar again it is necessary that this switch be moved to the required mode and the radar will operate whereupon the delay for warming up the equipment will not be required.

If the equipment will not be needed for a prolonged period of time or in the case of its failure it is necessary to turn the radar off completely, for which the "Off" key on the main indicator is pressed. Moreover, with the subsequent turning on, no matter how short the interval between turnings on was a 3-5 min delay will be required for warming up the equipment and an image can be obtained on the indicator only after this period.

## AIRBORNE RADAR ROZ-1

The ROZ-1 is a panoramic circular scan radar set which has four scales of scan: 20, 55, 110, and 200 km. The ROZ-1 has been provided with a sweep delay relative to the sounding impulses (30 and 160 km), making it possible to examine radar reference points at more distance ranges than at a scale of 200 km.

In this way with a delay of 30 km the first 50-km mark will be 80 km, and with a delay of 160 km - 210 km (Fig. 130).



Fig. 130. The sweep delay.

Reversible control of antenna rotation ensures the determining of the drift angle by the method of "Stopped antenna."

On the right side of the indicator below are the knobs intended for the control of the picture quality (Fig. 131) with the labels "Isolation" and "Foc." These knobs control the tonality of the image: dark tone - from a water surface, light - from terrestrial surface, and bright - from individual objects. These knobs separate the weak signal against the background of nosies or strong by retraction of weak, and also emphasize the signals reflected from a water surface. More to the right is a knob with label "Illumination of scale."

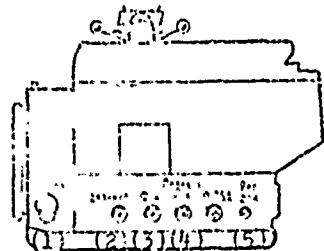


Fig. 131. Right side of indicator.  
KEY: (1) Scale; (2) Isolation;  
(3) Background; (4) Illumination  
of scale; (5) Reg. foc.

On the left side of indicator below (Fig. 132) are the knobs with the labels: "Bright. Screen," "Bright. Mark," a switch with the label "Azimut. mark," intended for turning on the signal of the azimuthal mark. On the front of the indicator are: to the right a knob with the label "Scale" for control of the scale and on the left - a knob with the label "Sight" for the control of the sight of the indicator.

The remaining knobs are intended for operations on the maintenance of the locator.

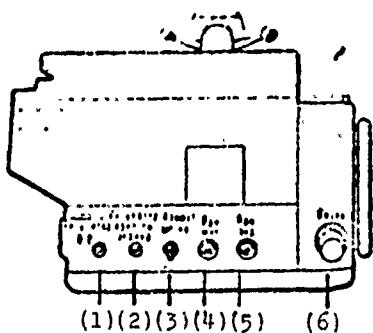


Fig. 132. The left side of indicator.

KEY: (1) Regulator W; (2) Regulator of screen brightness; (3) Azimut. mark; (4) Bright. mark; (5) Bright. screen; (6) Sight.

On control panel (Fig. 133) there are: switch 1 for power supply of the radar with the label "power supply;" it has two positions "On" and "Off;" switch 6 for high voltage of the transmitter with the label "transmitter;" it has two positions "on" and "off;" switch 18 of the control device for the control of operating conditions: the measurement of rectified voltages of the currents of crystals, the current of the magnetron and voltage of the pressure sensor in the pressurized section of the transmitter. On the switch there are the appropriate labels; switch 15 for scanning scales with the label "Scale" and four positions: "20," "55," "110," and "200;" switch 11 for delay of scan with the label "delay" and with three positions: "0," "30," and "160;" knob 9 for slant of antenna dish with label "Antenna slant" and two directions of movement "Up" and "Down." Over this knob for controlling the setting of the antenna angle is indicator

4 with the appropriate numbering; switch 10 with the label "Rotation of antenna" has two positions: "On" and "Manual," In the overhead position of the switch ("On") the antenna has continuous circulation, while in the down position of the switch ("Manual") the antenna is stopped and changed over to manual control; knob 13 of the switch for rotation of the antenna by hand with the label "Left-right." In this mode the direction of rotation of the antenna will be determined by the direction of pressure on the knob; knob 12 for regulating the rate of rotation of the antenna during the manual control with label "Rate. manual;" knob 17 for the regulation of receiver amplification with the label "Amplification of receiver;" knob 8 for the manual tuning of frequency with the label "Tuning;" knob 7 for turning on the AFC with two labels: "AFC" and "MFC;" knob 16 for turning on the beacon with the label "Beacon" and two positions: "On" and "Off;" knob 14 for the brightness control of dial lights with the label "illumination;" monitor 3 with switch 18, intended for the measurement of the basic supplying voltages and currents with the appropriate setting of the switch; warning lamps: turning on of the power supply of station - green 2 - on the left above, the turning on of high voltage - red 5 - on the right above and red dial lights for the face panel.

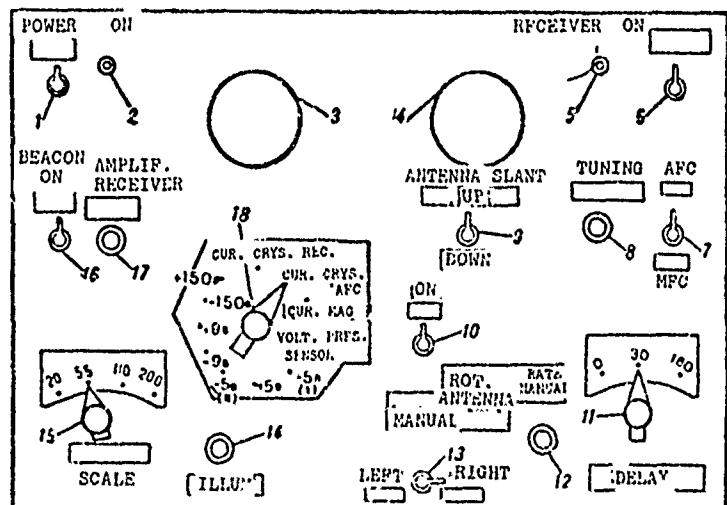


Fig. 133. Control panel of the radar set.

## The turning on and functional check of the ROZ-1

Before take-off when connecting to the aircraft electrical system of the airport power source or after starting the engine the operation of the ROZ-1 is checked in this sequence:

1. The controls before turning on are set in the following manner: power switch - in the position "Off"; the switch "transmitter" - in the "Off" position; the switch "Delay" - in the "0" position; switch "Rot. ant." - in "Manual" position; switch "Beacon" in the "Off" position; switch "AFC-MFC" - in the position "MFC"; knob "Amplification of receiver" - in the extreme left position by counter clockwise rotation; knob for antenna rotation rate by hand ("Rate. manual") - in extreme left position by counter clockwise rotation; knob for "Illumination" of panel - in extreme left position by counter clockwise rotation; switch "Azimut. mark" - in the "Off" position; knob "Bright. screen" - in the extreme left position by counter clockwise rotation; knob "Background" - in the extreme left position by counter clockwise rotation; knob "Isolation" - in the extreme left position by counter clockwise rotation; knob "Illumination" of scale - in the extreme left position by counter clockwise rotation.
2. After setting the control knobs in the indicated positions check on the voltmeter the voltages 115 V (400 Hz) and 27 V.
3. Turn on the radar, having placed the switch "power supply on" in the overhead position. In this case the dial lights on the face panel and the green warning lamp on it (next to the toggle switch "power supply on") should be lit up. By rotation of the knob "Illumination" adjust the illumination of the panel.
4. On the monitor on the control panel check the basic supply voltages (pointer should be within the limits of the appropriate sectors).

5. Regulate the luminance of the brightness of the sweep trace by clockwise rotation of the knob "Bright. screen."

6. Rotation of the antenna is turned on by setting the switch "Rotate antenna" in the overhead position.

7. For determining the efficiency of the receiving circuit "based on noises" on the screen of the radar it is necessary to set the "background" knob clockwise in the extreme right position and by the rotation of the knob "amplification of receiver" attain the appearance of "noises" on the indicator screen. After this the knob "Bright. screen" is used to attain such a luminance of brightness of scan at which "noises" remain still visible on the screen.

8. Attain the appearance of scale marks in the form of bright fine rings by rotation of the knob "Bright. mark" clockwise to the right.

9. Check the correctness of the range scales. For this the "Scale" knob is set successively in the positions "20," "55," "110", and "200." After testing the knob is set in the "20" position.

10. Change in the slope angle of the antenna dish is checked by instrument, for which the switch "Antenna slant" is held successively in the "up" and "down" positions.

11. Check the manual rotation of the antenna, for which the switch "Rotate antenna" is placed in the position "Manual" and by pressure on the "right" and "left" be convinced of the rotation of the antenna. Then the switch "Rotate antenna" is returned to the "On" position.

12. Check the currents of the crystals of the receiver and the AFC, for which the switch of the control device on the control panel is set in the position "Current cryst. receiv" and by

rotation of the "Tuning" knob attain the peak value of the current of the receiver crystal. After this set switch key in the position "Current crystal AFC." The pointer of the instrument should be located within the limits of the established sector.

13. Check the current of the magnetron. For this place the switch "Transmitter on" in the overhead position, whereupon the switch of the control device is placed in the position "Current of magnetron." At this its pointer should be located within the limits of the appropriate sector.

14. By rotation of the "Tuning" knob attain the appearance of reflected signals from reference points and maximum luminance of their brightness.

With the setting of the "AFC-MFC" switch in the position "AFC" there should be no deterioration in the brightness of radar reference points.

15. Check the operation of the video amplifier by means of setting the "Isolation" knob in the extreme right position by clockwise rotation. The brightness of the radar image should increase.

16. Check the presence of scanning at various delays, setting the "Delay" switch in turn in the positions "30" and "160." On the termination of testing return the switch to the "0" position.

When taxiing for takeoff from the flight line the navigator is obliged to set the switch "Rot. antenna" in the down position and only after the lift-off of the aircraft from the RW to transfer it to the overhead position for the superstructure.

## Some Breakdowns in the Operation of the ROZ-1 Radar in Flight and Their Elimination

During operation with ROZ-1 equipment it must be borne in mind that:

1. In the AFC system search is absent. In the case of the disappearance of display (when the current of magnetron, mixers and noises exists) it is necessary to set the "MFC-AFC" switch in the position "MFC," with the "Tuning" knob adjust the radar to the maximally observed distance based on the background of the earth, and after this return the switch to the position "AFC." If with this the image dampens or disappears, then continue the operation of the radar with the toggle switch in the position "MFC."

2. On TU-124 and TU-134 aircraft the pressurized part of the radar is boosted from the pressurized cabin and with a lowering of pressure in it to less than 500 mm Hg the transmitter should be turned off to avoid breakdown.

In the cases of disruption of scan on the radar screen and variations of magnetron current it is necessary to set the control switch on the control panel in the position "Volt. pressure sensor." If the pointer of the control device is located left of the vertical line of the dial face, then this attests to a lowering of pressure in the pressurized section below 500 mm Hg and the transmitter should be turned off.

The transmitter can be turned on only when the pointer of the control device is located to the right of the vertical graduation mark, i.e., when pressure in the pressurized section is above 500 mm Hg cm.

3. In the ROZ-1 there is the possibility of the random blowing out of fuses due to their aging.

#### Switching Off the Radar

1. Before landing it is necessary to stop the rotation of the antenna and to turn off the high voltage.

2. After the landing turn off the power supply of the radar.

3. After switching off of the radar all control knobs and controls should be placed in the original position.

Table 33. Failures in the ROZ-1 in the case of blowing out of fuses.

Number of fuses	Circuit, V.	Unit	The signs of failure
Pr-1 0.25A	~115	LTs-6	There is no scan, the azimuth scale is not illuminated
Pr-2 1A	+27	LTs-21	Set not turned on with the power switches in the "On" position
Pr-3 2A Pr-5 5A	+27 +27	LTs-1 and Sh-15-5 LTs-28	Slant of antenna does not work. Azimuth marks absent on the screen of the indicator with the "Azimut" mark switch turned on
Pr-6 2A	~115	LTs-6, TR-1. Tr-2 in unit LTs-15	On the monitor of the control panel all supply voltages are absent.

Table 33. Continued

Number of fuses	Circuit, V	Unit	The signs of Failure
Pr-7 10A	+27	LTs-1, LTs-2-12, LTs-21	Slant of antenna does not work, the range scales are not changed over, there is no illumination of the scale of unit LTs-21, there is no high voltage, transmitter not turned on
Pr-8 10A	~115	LTs-2-12	There is no magnetron current
Pr-9 2A	~115	LTs-1	Antenna does not rotate along azimuth

If after the replacement of a fuse its repeated burnout occurs, the radar must be turned off.

## THE ORDER OF OPERATION WITH A PERISCOPIC SEXTANT

Using the observations of celestial altitude it is possible to solve the following navigational problems:

to lay one astronomical line of position (ALP) on the sun for the control of course for distance or direction during daylight flight;

to locate the aircraft position (MS) by plotting two ALP on a chart based on two navigational stars or one star in a complex with Polaris in flight at night.

In the daytime in flight to the east or west control of the course for distance (on the sun) can be accomplished in the morning and evening hours, control of the course for direction - at noon.

In flight to the north or south, on the contrary, the control of the course for distance is easily accomplished at noon, and for direction - in the morning or evening hours.

In cases when ALP passes to the track at an angle close to  $45^\circ$ , then it can be used only in conjunction with some other position line.

If in night flight the MS is determined by the altitude of the Polar and other navigational stars, then the second star should be found in the east or west.

When determining the MS from any another pair of celestial bodies it is important that their azimuths differ by an angle close to a straight line. The calculation of one ALP based on the sun, moon, or a planet is carried out in a form as shown in Table 38. For this:

1. Record the time of measurements of the celestial altitude  $T$ .

2. Record the measured celestial altitude  $h_{\text{изм}}$ .

3-4. Record the longitude and latitude of enumerated point  $\lambda$  and  $\phi$ .

5. Determine  $T_{rp}$  according to the formula  $T_{rp} = T_n - N$ .

6-7. From the AAE (Air Almanac) write down the star declination  $\delta$  and its western hour angle  $t_{rp}$  for a whole number of hours. For the moon also record the parallax.

8. On an interpolation table find and record the correction for  $t_{rp}$  for minutes and seconds  $T_{rp}$ .

9. Determine the local hour angle of the celestial body  $t_m$ , and adding the  $t_{rp}$  correction to it for minutes and seconds  $T_{rp}$ , and  $\lambda$ , in this case increasing or decreasing  $\lambda$  of the enumerated point is attained in order that  $t_m$  would be expressed by the whole even number of degrees.

If the western hour angle is obtained greater than 180, then a supplement to it up to  $360^\circ$  is taken and the hour angle is considered eastern.

10-11. Extract from the [TVA] (TBA) [Tables of altitude and azimuths of stars] the values  $h_B$  taking into account the correction for the minutes of declination and value A. If the hour angle is western, then as azimuth assume the supplement of its tabular value to  $360^\circ$ .

Table 38. Calculation of one ALP based on the sun, the moon or a planet.

Order of operation	Date	Celestial body
	W WY	H Hh
1	T	
5	$T_{rp}$	
6	$t_{rp}$	
8	Correction $\Delta t_{rp}$	
4	$\lambda_{\Pi}$	
9	$t_M$	
3	$\phi_{\Pi}$	
7	$\delta$	
2	$h_{\text{иэм}}$	
13	C	
14	r	
15	q	
16	$h_{\text{исп}}$	
10	$h_B$	
17	$\Delta h$	
18	$\Delta h_{\text{иэн}}$	
11	A	

12. Determine the course bearing of the celestial bodies:  
 $\Delta\Delta = A - \Delta\gamma$ .

13-15. Write out on a form the corrections: sextant C, for refraction r, for the rotation of the earth q.

16. Amend the measured celestial altitude by the extracted corrections.

17. Calculate  $\Delta h' = h - h_B$ .

18. Convert  $\Delta h$  into kilometers.

After the operations conducted plot the ALP on the chart, for which:

plot the enumerated point with the corrected longitude;

through the enumerated point plot the azimuth line of the celestial bodies. If  $\Delta h > 0$ , then plot the segment equal to  $\Delta h$  in kilometers in the direction from the enumerated point to the celestial body. If  $\Delta h < 0$ , then the segment is plotted in the direction from the celestial body;

through the end of the plotted segment perpendicular to the azimuth line construct the ALP.

When determining the MS from the intersection of the ALP from two navigational stars the order of calculation remains as previous. Exceptions are:

the measurements and recording of the time of reading are carried out consecutively for two celestial bodies;

instead of Greenwich and local hour angles  $t_{rp}$  and  $t_m$  the Greenwich and local sidereal times  $S_{rp}$  and  $S_m$ ;

instead of the TVA tables the TVAZ tables compiled on sidereal time are used. With this the value of azimuth is always obtained real without supplements up to  $360^\circ$ ;

as a result of the time difference in the measurement of the altitude of the first and second celestial body it is necessary to introduce the correction E for movement of the first ALP during the time between measurements;

the position of the aircraft is defined as the point of intersection of the two ALP.

The order of accomplishing the recordings and calculations is numbered in the first column of Table 39.

Determining the MS by the altitude of the polar and one navigational star is most favorable from the point of view of the effectiveness of astronomical calculations. The order of calculation is shown in Table 40.

For western or eastern star it almost completely coincides with the order of solution by two navigational stars, while for polar the number of recordings is reduced.

Correction D for the movement of the aircraft between the moments of measurements is taken for Polaris based on the correction card E, but with a reverse sign, since the altitude of Polaris is measured later than the altitude of the first celestial body.

Table 39. The calculation of two ALP based on stars for determining the MS.

(A)	(B)		
11		1 celestial body (C)	2 celestial body (C)
5	$T$ $T_{rp}$		
6 7 4	$S_{rp}$ $\Delta S_{rp}$ $\lambda$		
8 3	$S_n$ $\tau$		
2 12 13 14 15	$h_{n,0}$ $C$ $-r$ $q$ $L$		
16 9	$h_{n,0}$ $h_B$		
17 18 10	$\Delta h$ $\Delta h_{n,0}$ $\lambda$		

KEY: (A) Order of operation; (B) Date; (C) Celestial body.

If navigator considers that the course of aircraft during the operating time of the averager was not changed, then instead of correction E it is more convenient to take a correction for the rotation of the earth (in km). In this case the MS should be shifted by the indicated correction in the northern hemisphere to the right, in the southern - to the left from the track.

Table 40. Determining  
MS by altitude of  
polar and one naviga-  
tional star.

(A)	(B)		
Operation	$h_{...}$	$w_{...}$	$uv_{...}$
13	1 северное III (C)	Звезда (D)	Полярная (E)
6	$T$ $T_{rp}$		
7	$S_{rp}$		
8	$\Delta S_{rp}$		
5	$\lambda$		
9	$S_M$		
4	$\tau_B$		
2	$h_{BPM}$		
14	$C$		
16	$r$		
18	$h_{BPM}$		
21	$h_B$		
23	$\Delta h$		
11	$A$		
3	(E) $h_{BPM}$		
15	$C$		
17	$-r$		
19	$h_{BPM}$		
20	$D$		
12	$\Delta \tau_{BPM}$		
24	$\varphi$		

KEY: (A) Order of  
operation; (B) Data;  
(C) Celestial body;  
(D) Star; (E) Polar.

## ASTRONOMICAL CALCULATION AIDS

The aviation astronomical (AAE annual) is intended for obtaining the equatorial coordinates of the Sun, Moon, Venus, Mars, Jupiter, Saturn, and the brightest stars and for the calculation of the conditions of natural illumination, and also the rising, setting, and phases of the moon at assigned points and enroute. The AAE is put out yearly and consists of excerpt tables for every day which contain:

the moments of the visible rising and setting of the upper solar limb on the meridian of Greenwich for an observer who is located at sea level and their diurnal variations;

the duration of civil and nautical twilight for an observer who is located at sea level;

the moments of the visible rising and setting of the upper limb of the moon on the meridian of Greenwich for an observer who is located at sea level and their diurnal variations;

Greenwich hour angles  $t_{rp}$  for the moon;

quasi-difference  $\bar{\Delta}$  between two successive tabular values for the Greenwich hour angles of the moon;

declination of the moon  $\delta$  and difference  $\Delta$  between two successive tabular values of the declination of the moon;

correction of parallax  $p$  to the measured altitude of the moon;

the moment of onset of one of the four main phases of the moon;

Greenwich sidereal time  $S_{rp}$ ;

Greenwich hour angles  $t_{rp}$ , declination  $\delta$  and the right ascension  $\alpha$  of the sun;

Greenwich hour angles  $t_{rp}$  and the declination  $\delta$  of the planets Venus, Mars, Jupiter, and Saturn.

The AAE makes it possible to solve the problems:

determining the moments of rising and setting of the sun and moon;

determining the moments of onset and termination of twilight;

determining the areas of a nonsetting and nonrising sun;

determining of local hour angle  $t$  and the declination  $\delta$  of the sun, moon and planets at an assigned moment;

determining the moments of culmination of celestial bodies;

determining of the right ascension  $\alpha$  of stars, the sun, moon, and planets;

determining the position of planets among the stars.

The tables of altitudes and azimuths of celestial bodies (TVA) and (TVAZ). For the calculation of the altitude and azimuth of celestial bodies the "Tables of altitudes and azimuths of the sun, moon, and planets" (TVA) and the "Table of altitudes and azimuths of stars" (TVAZ) are used.

The TVA is published in three books: TVA-I - for latitudes from 0 to  $\pm 30^\circ$ , TVA-II - from  $\pm 30$  to  $\pm 60^\circ$ , and TVA-III - from  $\pm 60$  to  $\pm 80^\circ$ .

The TVAZ is published in six books: three books for north latitudes and three for south. The TVAZ-I - for latitudes from 0 to  $32^\circ$ , TVAZ-II - for the latitudes from  $28$  to  $60^\circ$ , TVAZ-III - from  $56$  to  $88^\circ$ , TVAZ-S-I - for the latitudes from 0 to  $-32^\circ$ , TVAZ-S-II - from  $-28$  to  $-60^\circ$ ; and TVAZ-S-III - from  $-56$  to  $-88^\circ$ .

Input data for the determination of the altitudes and azimuths of celestial bodies with the help of TVA are:

the latitude of the place  $\phi$ , expressed by an even number of whole degrees;

the western or eastern local hour angle of the celestial body  $t$ , expressed by an even number of whole degrees;

the declination of the heavenly body  $\delta$ , expressed in degrees and minutes within the limits of  $\pm 29^\circ$ .

The tables are constructed for whole degrees of declination within the limits of  $\pm 29^\circ$ . The declinations, similar (on sign) with latitude, are given in the upper part of the tables, and dissimilar - in the lower.

Every column of a page corresponds to one of the even latitudes. It is divided into three parts: in the first the astronomical altitudes are given, in the second - factors  $f$  which are input data for the correction of altitudes for minutes of declination, and in the third - the azimuths of celestial bodies. Altitudes are given to within  $1'$ , and azimuths - to within 1.

In the appendices to every book correction cards are given for the astronomical altitude for minutes of declination, correction cards for the refraction of the atmosphere, for the rotation of the earth, for the movement of the aircraft, and tables for conversion of arc minutes of the great circle into kilometers.

The TVA are not connected with the continually changing concrete values of the equatorial coordinates of celestial bodies, therefore they can be used at any time regardless of the year of publication.

The input data for determination of the altitudes and azimuths of the stars with the help of TVAZ are:

the latituue of place  $\phi$ , expressed by an even number of whole degrees:

local sidereal time S, expressed by the integer of degrees;

the name of the star.

Along with the altitudes and azimuths of stars the TVAZ also contains corrections for the altitude of Polaris ( $\Delta\phi_{\text{поляр}}$ ). The altitudes of stars and corrections for the altitude of Polaris are given to within 1', and the azimuths of stars - to within 1°. When using the "Tables of the altitudes and azimuths of stars" one ought to focus attention on the year of the publication for which they are compiled. The tables can be used for  $\pm 4$  years from that year for which they were published.

Airborne celestial charts. For studying the celestial sphere and selection of and searching for stars the airborne celestial charts (BKN) are used. They are compiled for the

northern latitudes in three versions: BKN-I - for latitudes from 30 to 44°, BKN-II - from 46 to 60°, and BKN-III - from 62 to 70°.

With the help of BKN it is also possible to determine the approximate equatorial and horizontal coordinates of celestial bodies, the moments of rising, setting, and culmination of celestial bodies.

#### USE OF DAK-DB-5 ASTROCOMPASS IN FLIGHT

The DAK-DB-5 astrocompass ensures in flight the measurement of the true or orthodromic course of the aircraft.

A condition for the correct measurement of true course is the compensation of the rotation of the aircraft. In view of the fact that in the DAK-DB-5 astrocompass for compensation of bank a pendulum bank corrector is used, it is necessary to measure the true course only under the condition of forward flight or under the conditions of uniform climb or descent.

Another condition for the precision measurement of true course relative to the meridian of the position of the aircraft is the fine adjustment on the instrument of geographical coordinates  $\phi$  and  $\lambda$ . With this the measuring error of true course of the flight of the aircraft is also found in direct dependence on the solar angle.

Error in determining true course reaches the maximum values at high levels of the sun because of the inaccurate establishment of longitude. The permissible values of error in determining the position of an aircraft in the measurement of the flight course of an aircraft are shown in Table 41.

Table 42. Permissible  $\lambda_{y_{\text{сл}}}$  -  
 $\lambda_{\text{действ}}$

$\phi^{\circ}$	80	83	85	86	87
$\lambda^{\circ}$	18	28	44	58	84

The DAK-DB-5 astrocompass ensures the continuous determining of true course and its feeding to the indicators. By maintaining on the indicator a constant value of course, the airplane crew can perform flight on an assigned direction. The assigned route is usually plotted either with true (magnetic) course angles (IPU), or with orthodromic course angles (OPU).

For accomplishing flight from an IPU(MPU) the coordinates of the aircraft position are introduced into the astrocompass periodically by hand. In this way the aircraft is established on the calculated loxodromic course (logarithmic curve around PN) only at the moments of the setting of the actual coordinates  $\phi$  and  $\lambda$  on the calculator. In the intervals between the introduction of coordinates the aircraft will begin to deviate from the assigned heading and flight will occur on a certain curve similar to a rhumb line.

The magnitude of greatest deviation  $Z$  of the aircraft from the assigned route, indicated in Table 43, in flight on a rhumb line depends on the solar angle and length of stages of the route.

The calculations are made for a range of latitudes 40-70°.

Table 43.

Z (km)

h. deg	S. km				
	200	400	600	800	1000
10	0.4	0.9	1.8	2.8	4.1
30	1.1	1.8	4.6	9.3	14.0
50	2.4	4.6	10.5	18.5	29.6
70	5.0	11.0	21.0	43.0	63.0

From Table 44 it follows that at the solar angles up to 30 at 700 km stages of route the lateral deviations are so low that they can be disregarded. With an increase in solar angles the stages of the routes, on which the lateral deviations do not exceed 5 km, decrease: at solar angles of 30-50° - to 500 km, and at altitudes of 50-70° - to 300 km.

Table 44. Frequency of input of coordinates into the calculator of the astrocompass (hour min).

h. deg	Type of aircraft			
	Il-18	An-10	Tu-104	Tu-114
10	3.00	3.00	2.30	2.30
30	1.40	1.20	1.00	1.00
50	1.00	1.00	0.45	0.45
70	0.40	0.40	0.30	0.30

From the indicated relationships it is possible to determine the frequency of input of coordinates into the calculator of the astrocompass during flight on a rhumb line (Table 44). In this case it is proposed that the flight course of the aircraft is calculated taking wind into account.

For accomplishing flight on the great circle the astrocompass DAK-DB-5 contains a special instrument which compensates the movement of the aircraft in flight.

As a result of the operation of the course correctors the axis of search rotation of the plane of direction finding of the sighting system is always retained parallel to the vertical line of the departure point. With any turn of aircraft in a horizontal plane the axis of sighting system will depart from the correct position, since it will not be parallel to the vertical lines of the departure point. With this the sighting system will obtain supplementary rotation which will lead to an error in the course. This error will obtain the greatest value during flight to the sun or from it. In Table 45 the permissible angles of turn of an aircraft are indicated at which the error in the course does not exceed  $2^\circ$  on sections of the great circle of various length. The calculation was conducted for the solar angle  $h$ , equal to  $45^\circ$ , and the heading  $KU_{\text{солн}}$ , equal to 0 or  $180^\circ$ .

Table 45. The permissible angles of the turn of an aircraft.

Length of the section of orthodrome, km	200	400	600	800	1000
Permissible angle of turn, degrees	64	32	21	16	12

Error in the measurement of course during flight along the great circle appears also when there is a drift angle which is not considered by the course correctors. If we take the orthodrome section  $S = 1000$  km, drift angle  $US = 10^\circ$ , and solar angle  $h = 45^\circ$ , then the error in course will not exceed  $1.6^\circ$ . With an increase in the solar angle and in presence of drift angle the error in the measurement of course increases.

### *Astronomical numbers and dates*

The visible apparent diameter of the sun and moon.....	0.5°
Tilt of ecliptic to equator.....	23°27'
The mean radius of earth.....	6.371 km
The mean circumference of the earth's surface.....	40,000 km
Difference in the equatorial and polar radius of earth.....	21 km
The average distance from earth to moon.....	384,400 km
The average distance from earth to sun.....	149,500,000 km
The distance from the solar system to the nearest star (α Centaur).....	4.3 light years
The distance from the sun to the center of the galaxy.....	23,000 light years
The diameter of the galaxy.....	100,000 light years
The distance from the earth to the nearest galaxy - Andromedia nebula.....	1 million light years
Rate of movement of moon around the earth.....	1 km/s
The period of revolution of moon around the earth and the period of its rotation around its axis.....	27.5 solar days
Rate of movement of earth around the sun.....	30 km/s
Rate of movement of the sun with the solar system relative to stars (to the constellations of Lyra and Hercules).....	20 km/s
The rate of rotation of the sun and its surrounding stars around the galactic center.....	400 km/s
The period of rotation of the sun around its axis (at equator).....	25 days
Mass of earth.....	$6 \cdot 10^{21}$ m
The mass of the sun is greater than the mass of earth by.....	times

The diameter of the moon is less than the diameter of the earth by.....	4 times
The diameter of the sun is greater than the diameter of the earth by.....	109 times
The number of stars visible to the naked eye (on the entire celestial sphere).....	about 6,000
The surface temperature of sun.....	6,000°C
The temperature of stars from.....	3,000 to 30,000°C
Vernal equinox.....	21 March
Summer solstice.....	22 June
Autumnal equinox,.....	23 September
Winter solstice.....	22 December
The replacement of the cycle of lunar phases occurs every.....	29.5 days
Duration of day at north pole.....	189 days
Duration of night at north pole.....	176 days
The general duration of crepuscular time at the pole in spring and in autumn (solar angle from 0 to $-7^\circ$ ).....	29 days
Orbital velocities of artificial bodies (at the earth):	
circular,.....	7.9 km/s
planet escape.....	11.2 km/s
solar escape.....	16.7 km/s

#### THE INTERNATIONAL SYSTEM OF STANDARD TIME

The entire earth's surfaces is divided into 24 time zones by meridians distant from one another by  $15^\circ$ , which corresponds to a difference of one hour in time. The numbering of time zones is conducted from the zero zone, included between meridians  $7^\circ 30'$  east from the mean meridian of this zone - the Greenwich zero zone. To the east from the zero zone the zones are numbered

-1, -2, -3, ..., -12; their mean meridians respectively  $15^{\circ}$ ,  $30^{\circ}$ ,  $45^{\circ}$ , ...,  $180^{\circ}$  east from the Greenwich meridian; to the west from the zero zone the zones are numbered from +1 to +12.

Within the limits of every zone the hours should indicate mean solar time of the mean meridian of this zone (with the exception of the cases when in any state or area to the determined period of time it is introduced the so-called "summer time" or the hour hand is constantly moved forward with respect to the time of the given zone).

Readings of time in every two zones should differ by a whole number of hours equal to the difference in the numbers of these zones (the more eastern the zone the larger the readings of time).

Examples: 1. An aircraft is located in zone -2 and has on its clock the time of this zone. The clock shows 10 hours 5 minutes 10 seconds. What is the time in Greenwich? The answer: 8 hours 5 minutes 10 seconds.

2. In the zone +5 the time is 14 hours 51 minutes 9 seconds. What is the time in zone +3? The answer: 16 hours 51 minutes 9 seconds.

In practice the boundaries of time zones coincide with the boundary meridians only in open parts of the oceans and seas and in sparsely populated territories. On dry land, as a rule, they coincide with the state, administrative, or natural boundaries. The boundaries and the numbering of zones appear on the map of time zones.